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GLOSSARY OF ACRONYMS

BNL	Brookhaven National Laboratory
EF	Enhancement factor
FPD	Finite probability distribution
ICRP	International Commission on Radiological Protection
IMD	Individual medical and diet
IMSL	International Mathematics and Statistical Laboratory
LLNL	Lawrence Livermore National Laboratory
MLSC	Micronesian Legal Services Corporation
NCRP	National Council on Radiation Protection and Measurements
PDEF	Personal dosimeter enhancement factor
TTG	Trust Territory Government

AN UPDATED RADIOLOGICAL DOSE ASSESSMENT OF BIKINI AND ENEU ISLANDS AT BIKINI ATOLL

ABSTRACT

This report is part of a continuing effort to refine dose assessments for resettlement options at Bikini Atoll. Radionuclide concentration data developed at Bikini Atoll since 1977 have been used in conjunction with recent dietary information and current dose models to develop the annual dose rate and 30- and 50-y integral doses presented here for Bikini and Eneu Island living patterns.

The terrestrial food chain is the most significant exposure pathway--it contributes more than 50% of the total dose--and external gamma exposure is the second most significant pathway. Other pathways evaluated are the marine food chain, drinking water, and inhalation.

Cesium-137 produces more than 85% of the predicted dose; ^{90}Sr is the second most significant radionuclide; ^{60}Co contributes to the external gamma exposure in varying degrees, but is a small part of the total predicted dose; the transuranic radionuclides contribute a small portion of the total predicted lung and bone doses but do present a long-term source of exposure.

Maximum annual dose rates estimated for Bikini Island are about 1 rem/y for the whole body and bone marrow when imported foods are available and about 1.9 rem/y when imports are unavailable. Maximum annual dose rates for Eneu Island when imports are available are 130 mrem/y for the whole body and 136 mrem/y for bone marrow. Similar doses when imported foods are unavailable are 245 and 263 mrem/y, respectively.

The 30-y integral doses for Bikini Island are about 23 rem for whole body and bone marrow when imported foods are available and more than 40 rem when imports are unavailable. The Eneu Island 30-y integral doses for whole body and bone marrow are about 3 rem when imports are available and 5.5 and 6.1 rem, respectively, when imports are unavailable. Doses from living patterns involving some combination of Bikini and Eneu Islands fall between the doses listed above for each island separately.

Nearly all of the parameters in the dose models have log-normal distributions. Two different methods for developing the distribution in the final estimated doses, based on the distribution of each of the model parameters, indicate that the distribution of

estimated doses is also log-normal. The doses listed throughout are calculated with the average value for each of the model parameters and, as a result, fall at about the 68th percentile on the dose-distribution curve.

INTRODUCTION

BACKGROUND AND PURPOSE

A general cleanup of debris and clearing of Bikini and Eneu Islands in the eastern and southern portions of Bikini Atoll (Fig. 1) occurred in 1969. Coconut trees were planted on both islands and 43 houses were constructed on Bikini Island. The first resettlement of Bikini Atoll, after the Bikini peoples' initial relocation in 1946, occurred in 1970 when a few people elected to return and establish residence on Bikini Island. Over the years the number of Bikini people residing at the atoll has fluctuated.

In 1975, prior to the construction of a second phase of housing on Bikini Island, a radiological survey was conducted on Bikini and Eneu Islands to determine the best location for additional housing to reduce the external radiation exposure. At the same time, samples from the various food chains were collected, where available, and analyzed to evaluate the potential dose to inhabitants via the ingestion pathway. The results from this preliminary survey indicated that inhabitants of Bikini Island would receive much larger doses than those living on Eneu Island.[1-5] Other conclusions from that survey indicated that the terrestrial food chain is the greatest source of potential dose to a returning population, ^{137}Cs and ^{90}Sr will be the most significant radionuclides over the next few decades, and transuranic radionuclides present a small but long-term exposure at the atoll. However, at the time of the 1975 survey very few samples of locally grown food crops were available to effectively and confidently establish their radionuclide concentrations on the two islands and, therefore, to reliably estimate doses to inhabitants of the islands.

Coconut trees had been planted in 1970 by the Trust Territory Government (TTG) on both islands and Pandanus and breadfruit trees had been planted on Bikini Island, the site of the first phase of housing construction. However, none of these food crops were producing fruit in 1975, whereas a few of the older coconut trees and some wild Pandanus trees that survived the cleanup were.

As part of the continuing effort to refine the dose estimates for resettlement options at Bikini Atoll, a test garden was established on Eneu Island in August of 1977. Its purpose was to provide samples of locally grown food crops, in addition to the coconut trees that had been planted by the TTG, to develop uptake and concentration data for a

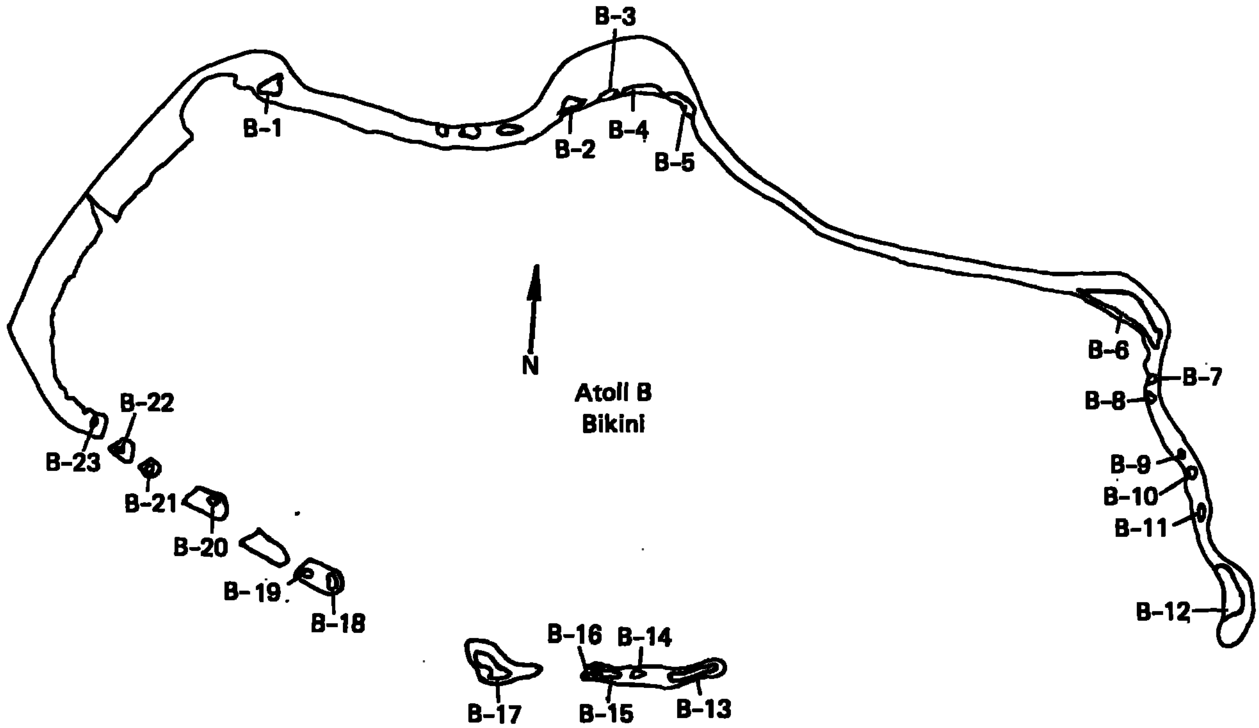

Figure 1. Bikini Atoll. Code letter and numbers indicate various islands--Bikini Island, B-6 and Eneu Island, B-12.

greater variety of food crops and to evaluate Eneu Island as a residence and agricultural island. The food crops planted on Bikini Island in 1970 by the TTG and by the people subsequent to resettlement in 1970 provide samples that are used to evaluate that island.

Papaya, banana, squash, and watermelon were harvested approximately 15 mo after the Eneu test garden was established. In addition, the coconut trees planted by the TTG on both islands started to bear nuts in 1978 and 1979. The breadfruit and Pandanus fruit on Bikini Island started bearing fruit in 1978. As a result we collected, processed, and analyzed those locally grown food crops that have been available through March of 1979. The samples collected during 1980 and 1981 are currently being analyzed. The data developed from these samples and the associated soil profile data are used here to refine the estimated doses for a population that might resettle Bikini or Eneu Islands.

LIMITATIONS OF THE ASSESSMENT

The programs to develop better data on concentration and uptake of radionuclides in subsistence foods were begun on Bikini Atoll in August 1977 by planting test plots of breadfruit, Pandanus sp., papaya, banana, squash, sweet potato, and watermelon. The

TTG sponsored a large-scale coconut planting program on Bikini and Eneu Islands from 1970 to 1971; some breadfruit and Pandanus sp. were also planted on Bikini Island. Samples of annual crops (papaya, banana, squash, watermelon, and sweet potato) were collected in the first 1.5 y after the test plot was established. The trees planted at Bikini Atoll in 1970 have begun bearing fruit only in the past 3 y. Uptake and concentration ratio data (plant to soil) are developed from these subsistence crops whenever samples are available. However, the data base for each subsistence crop is not as large or complete as it will be in two or three more years.

The marine environment and the groundwater have been studied at Bikini Atoll since 1974 and these studies have supplied more complete data for evaluating those pathways. More data are needed to evaluate the radionuclide concentrations in cistern water at Eneu Island, however.

More recently, rather detailed experiments have been conducted at Bikini Atoll to determine the rate and source of resuspended aerosols and to provide the data needed to evaluate the inhalation pathway. Some continuing experiments at Eneu Island will supply additional data.

A very critical aspect of the dose assessment is the assumed average dietary intake of all foods for the returning population. The estimated doses will correspond directly with the activity (pCi/d) ingested from local food products.

Therefore, once the concentration of radionuclides has been determined for the foods and soils, the assumed diet becomes very important for estimating the activity that will be ingested. In the past, the diet we established was based on limited, early literature reports and limited direct observation. In 1978 we were ready to initiate diet studies of the people living on Bikini Island. However, about this same time the TTG began a large-scale program of supplying imported foods to the atoll. Furthermore, subsequently the people were relocated in August of 1978. As a result, we obtained no data concerning the intake of locally grown foods for the Bikini people living at Bikini Atoll. More recently, however, the Micronesian Legal Services Corporation (MLSC) conducted a medical and dietary survey of the Enewetak people at Ujelang Atoll. The results are given in Appendix A.* Because we have seen a great similarity between the dietary and living habits of the Enewetak and Bikini people and because the MLSC survey is the most direct information available on the dietary habits of the people of Enewetak, we have used the results in our assessment, even though it is not certain to what extent resettlement at Bikini or Enewetak Atoll will change the dietary habits of the people as observed at Ujelang.

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* Appendices are available from the authors on request.

A recent report from the Brookhaven National Laboratory (BNL), available to us after we made the dose calculations based on the MLSC survey and they were incorporated in a Department of Energy publication for the Bikini people, gives estimates of the quantity of food produced per household from observations made at Rongelap, Utirik, and Ailuk Atolls.[6] In the BNL survey, the average daily amounts of coconut fluid, coconut meat, and Pandanus meat prepared are higher than the average daily amounts consumed in the MLSC Ujelang survey. The fact that the BNL study is based on quantity of food prepared and not necessarily the quantity consumed and the fact that the observations were not of the Bikini people make it uncertain as to whether these observations are any more applicable to the Bikini Atoll situation than those from the MLSC survey. However, the BNL estimates are the highest average for either preparation or consumption amounts that we have found in the literature. Therefore, a calculation is made using the higher BNL values for coconut meat, coconut fluid, Pandanus, and fish to indicate the magnitude of the estimated doses if the average daily intake was this high. Again, it is not certain that these higher values are appropriate for an average daily intake for people residing at Bikini Atoll. In the next few years we hope to develop a dietary model based on direct observation of the people who may resettle Eneu Island and the people at Kili. However, not until an abundance of locally grown foods becomes available at Eneu and the lifestyle stabilizes will we be able to narrow the dietary uncertainties.

It is very important to again emphasize how dependent the estimated doses are on the dietary habits that are assumed and the importance of having atoll-specific dietary information.

DATA BASES

The exposure pathways for persons resettling Bikini Atoll consist of two major categories: external and internal exposure.

The specific pathways in each category are as follows.

1. External exposure
   a. Natural background
   b. Man-made gamma and beta rays
2. Internal exposure
   a. Radionuclides inhaled
   b. Radionuclides in drinking water
   c. Radionuclides in terrestrial foods
   d. Radionuclides in marine foods

The natural background at the atoll is 3.5 μR/h (microroentgen per hour) or 22 mrem/y (milliroentgen equivalent, man per year) and results primarily from cosmic radiation. The natural background is not included in the doses presented here.

EXTERNAL EXPOSURE--IN SITU MEASUREMENTS

External exposure rates for ^{137}Cs, ^{60}Co, and ^{241}Am were obtained from in situ measurements performed by EG&G as part of the Northern Marshall Islands Survey.[7] These measurements were made with 40 12.7-cm-diameter by 5.1-cm-thick sodium iodide (NaI) scintillation detectors mounted on two pods on a Sikorski SH3 helicopter. Flight lines were flown on a 46-m grid at an altitude of 38 m over the islands. For a detailed description of this methodology, see Ref. 7. The average external exposure for Bikini Island is 31 μR/h for ^{137}Cs and 1.9 μR/h for ^{60}Co and for Eneu Island it is 2.3 and 0.2 μR/h, respectively. The external gamma doses presented here are based on the island average external exposure (Appendix B). However, the Marshallese spend considerable time (30 to 50%) in or around the housing area. As a result, the housing provides shielding that reduces the average outside exposure by a factor of two. Also, coral gravel spread 20 to 40 ft around houses, a common practice in the Marshall Islands, will reduce the external exposure by another factor of two (see Ref. 1).

The result is that the external gamma doses presented here are probably upper limits because, depending on how much time one wishes to estimate is spent in and around the housing area, the external exposures will be considerably reduced because of shielding by the house and gravel. In addition, if the housing were located near lagoon roads the average external gamma exposure will be much less than in the interior of the island, so selection of the housing site can also make a significant difference.[1]

INHALATION

Airborne concentrations of respirable $^{293+240}Pu$ and ^{241}Am are estimated from data developed in resuspension experiments conducted at Bikini Atoll in May 1978. We briefly describe the resuspension methodology here; further details can be found in a paper summarizing the studies at Enewetak and Bikini Atolls.[8]

The study conducted on Bikini Island in May 1978 provided a more complete set of data than our preliminary studies on Enjebi (Janet) Island of Enewetak Atoll in February 1977. (Subsequent studies were conducted on Eneu Island at Bikini Atoll.) The Bikini Island study used extensive soil sampling and in situ gamma spectroscopy to determine isotope concentrations in soil and vegetation, various air-sampling devices to determine particle size distribution and radioactivity, and micrometeorological techniques to determine aerosol fluxes. Four simultaneous experiments were conducted: (1) a characterization of the normal (background) suspended aerosols and the contributions from sea spray off the windward beach leeward across the island, (2) a study of resuspension of radionuclides from a field purposely laid bare by bulldozers as a worst-case condition, (3) a study of resuspension of radioactive particles by vehicular and foot traffic, and (4) a study of personal inhalation exposure using small dosimeters carried by volunteers during daily routines. Less complete studies similar to (1) and (2) had been performed previously on Enjebi (Janet) and background studies similar to (1) were later performed on Eneu.

The normal or background mass loading measured by gravimetric methods for both atolls is approximately 55 $\mu g/m^3$. The Bikini Island experiments show that 34 $\mu g/m^3$ of this total is from sea salt, which is present across the entire island as a result of ocean, reef, and wind action. The mass loading from terrestrial origins is therefore about 21 $\mu g/m^3$. The highest terrestrial mass loading observed was 136 $\mu g/m^3$ immediately after bulldozing.

Concentrations of $^{239+240}Pu$ have been determined for (1) collected aerosols for normal ground cover and conditions, that is, normal conditions in coconut groves; (2) areas being cleared by bulldozers and being tilled, that is, high-activity conditions; and (3) stabilized bare soil, that is, the cleared areas after a few days of weathering. The plutonium concentration in the collected aerosols changes relative to the plutonium concentration in surface soil for the various situations. We have defined an enhancement factor (EF) as the $^{239+240}Pu$ concentration in the collected aerosol mass divided by the $^{239+240}Pu$ surface soil (0 to 5 cm) concentration.

The EF obtained from standard high-volume air samples (hi vols) for normal conditions is less than 1; the EF for worst-case, high-activity conditions is 3.1. Table 1 summarizes the observed EF at Bikini Atoll. The EF of less than 1 for hi vol data for normal, open-air conditions is apparently the result of selective particle resuspension in which the resuspended particles have a different plutonium concentration than is observed in the total 0- to 5-cm soil sample. In other words, the particle size and density and the corresponding radionuclide concentration is different for the normally resuspended material than for the total 0- to 5-cm soil sample. In addition, approximately 10% of the mass observed on the filter is organic matter, which has a much lower plutonium concentration than the soil. Similarly the enhancement factor of 3.1 for high-activity conditions results from the increased resuspension of particle sizes with higher plutonium concentration than observed in the total 0- to 5-cm soil sample.

We have developed additional personal dosimeter enhancement factors (PDEFs) from personal dosimeter data. These data are normalized to the hi vol data for a

Table 1. Pulmonary deposition of plutonium ($^{239+240}Pu$) for worst- and best-case conditions on Bikini Atoll.

Condition	Inhalation rate (m^3/h)	Dust aerosol (g/m^3)	Soil Pu activity (aCi/g)	Enhancement factor	Personal dosimeter factor	Respirable fraction	Pulmonary deposition (aCi/h)
Bare field, during tilling	1.04	136	15.3	3.1	0.92	0.24	1476
Stabilized field, heavy work	1.04	21	15.3	0.83	2.64	0.19	139
In and around houses, light work	0.83	21	15.3	0.83	1.86	0.19	78
Coconut grove, light work	0.83	21	8	0.41	1.1	0.19	12
At roadside, one vehicle/h[a]	0.023	28	4.1	2.5	1[b]	0.24	1.58 + BG[c]

[a] Exposure to one 10-s, median, vehicular dust pulse not including background (BG).

[b] Assumed value.

[c] Radionuclides inhaled via background mass loading.

particular condition and represent enhancement that occurs around an individual because of his daily activities (different from the open-air measurement made with the hi vols). These data are also summarized in Table 1. The total enhancement used to estimate the amount of respired plutonium is the combination of the hi vol and personal dosimeter values. The effective enhancement used for normal conditions is 1.54 and for high-activity conditions it is 2.9.

In the scenario adopted for the calculations we assume that a person spends 8 h/d under high-activity conditions and 16 h/d under normal conditions. Finally, a breathing rate of 23 m^3 per day (9.6 m^3 under high-activity conditions and 13.4 m^3 under normal conditions)[9] and the surface soil concentration (0 to 5 cm) for each island are used to complete the calculation for plutonium and americium intake via inhalation.

The International Commission on Radiological Protection (ICRP) lung model is used to estimate the lung and bone doses.[10] A pulmonary fractional deposition of 0.3 is used in the inhalation lung model; at this time we feel it is conservative from a dose-assessment point-of-view because preliminary analysis of the particle size distribution for both normal and high-activity conditions at Bikini Atoll indicate that the pulmonary deposition would be less than 0.3 (Table 1). The gut transfer factors used for $^{239+240}Pu$ and ^{241}Am are 10^{-4} and 5×10^{-4}, respectively, as recently suggested by the ICRP[11]; both plutonium and americium are considered to be class-W particles.

The dose contribution from the inhalation pathway is a major source of exposure to the transuranic radionuclides, but both the inhalation pathway and the transuranics will contribute a minor portion of the total doses predicted over the next several decades. The transuranic radionuclides that must be considered in evaluating the inhalation pathway are $^{239+240}Pu$, ^{241}Pu, and ^{241}Am as well as the ^{241}Am that in the future will result from the radiological decay of ^{241}Pu currently present. Because of the low-energy beta radiation (0.021 MeV maximum) and a much shorter half-life (14 y) the doses from ^{241}Pu are less than one tenth those from $^{239+240}Pu$.

The concentrations of ^{241}Am in the soil (pCi/g) at Bikini and Eneu are approximately 70 to 75% of the $^{239+240}Pu$ concentrations. However, more ^{241}Am will result from the decay of ^{241}Pu. The parent-daughter relationship for ^{241}Pu to ^{241}Am is shown in Fig. 2. The maximum ^{241}Am activity that will result from an initial ^{241}Pu activity is 2.6% of the initial ^{241}Pu activity. Because the present ^{241}Pu activity in the soil is about seven times that of $^{239+240}Pu$, the final ^{241}Am soil activity resulting from the decay of ^{241}Pu will be 0.18 that of $^{239+240}Pu$. The currently observed ^{241}Am soil concentrations are 0.7 that of $^{239+240}Pu$. Thus, the final total soil concentration of ^{241}Am resulting from ^{241}Am now present and that resulting from ^{241}Pu decay will be 0.88 (0.7 + 0.18) that of the existing $^{239+240}Pu$ soil concentrations. For estimates of dose via inhalation, the eventual ^{241}Am soil concentrations can be considered equal to the $^{239+240}Pu$ concentrations. As a result, the doses calculated for $^{239+240}Pu$ can be doubled to account for the ^{241}Am.

DRINKING WATER

The drinking water pathway contributes a very small portion of the total dose received via all pathways. However, we have included an evaluation to demonstrate its relative contribution and to complete the assessment of all major pathways.

The radionuclide concentration data used to evaluate the drinking water pathway are listed in Table 2. Cistern water is preferred and most often used; however, well water is used when drought conditions exist. When well water is used, the suspended material is allowed to settle out prior to consumption. In addition to drinking water, the Marshallese consume considerable quantities of coffee and Kool-Aid (Malolo) for which they again primarily use cistern water. The total fluid intake using cistern water and well water was determined to be approximately 1 liter/d according to the MLSC survey at Ujelang Atoll (Appendix A).

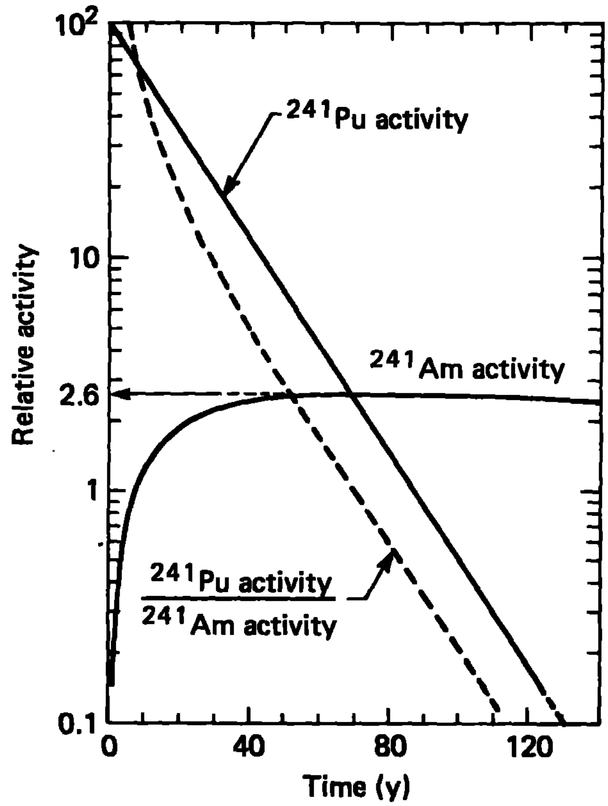

Figure 2. Relationship between parent ^{241}Pu activity and daughter ^{241}Am activity.

Table 2. Measured radionuclide concentrations in water for Bikini and Eneu Islands.

Type of water	Radionuclide concentration (pCi/liter)			
	^{137}Cs	^{90}Sr	$^{239+240}$Pu[a]	^{241}Am[a]
Bikini Island				
Groundwater[b]	430	115	45×10^{-3}	22×10^{-3}
Cistern water[c]	1.9	0.61	6.3×10^{-3}	3.2×10^{-3}
Eneu Island				
Groundwater[b]	31	31	9.2×10^{-3}	4.6×10^{-3}
Cistern water[c]	0.31	0.24	4.5×10^{-3}	2.3×10^{-3}

[a] Includes particulate fraction.

[b] Reference 12.

[c] Reference 13.

TERRESTRIAL FOODS

Soil Radionuclide Concentrations

The soil sampling program at Bikini Atoll started with the 1975 survey[1-5]; subsequent to initiating our field program at Eneu Island in 1977 we have continued to sample the soil at both Bikini and Eneu Islands.

All soil profile samples are collected for the following increments: 0 to 5 cm, 5 to 10 cm, 10 to 15 cm, 15 to 25 cm, 25 to 40 cm, and 40 to 60 cm. We have found that the 40-cm depth encompasses most of the active root zone of the subsistence crops that we have observed in the Northern Marshall Islands. A trench is dug with a backhoe radially from each sampled tree or in an open area not associated with a food crop. Samples are collected down the sidewall of the trench after the sidewall is scraped to avoid any possible contamination from the digging process. The 0- to 5-cm sample is collected from a surface area about 25 cm on a side. The area is then expanded by about 10 cm on each side and cleared to a depth of 5 cm. The upper surface (1 to 2 cm) of this enlarged area (35 by 35 cm) is then cleared to ensure that neither surface soil nor soil from a preceding increment has fallen on the next increment to be sampled. The next sample is then taken from the entire depth of the increment (i.e., 5 to 10 cm) from an area about 25-cm square within the enlarged region. This procedure is repeated until the final increment of 40 to 60 cm has been collected. A total of approximately 500 to 1000 g of soil is collected for each profile increment.

The soil samples are dried and ball-milled to a fine powder. Samples are then analyzed by gamma spectroscopy to determine the ^{137}Cs and ^{241}Am concentrations and by radiochemical procedures to determine the concentrations of ^{90}Sr; $^{239+240}$Pu; and in some cases, ^{241}Am and ^{241}Pu. Gamma spectroscopy of the soil samples for ^{137}Cs and ^{241}Am is accomplished using high-resolution, solid-state, germanium-diode systems. The ^{90}Sr, $^{239+240}$Pu, ^{241}Am, and ^{241}Pu are analyzed by radiochemical procedures by contract laboratories.

Radionuclide concentrations for the profiles 0 to 5 cm, 0 to 10 cm, 0 to 15 cm, 0 to 25 cm, 0 to 40 cm, and 0 to 60 cm are calculated using equal weights for each 5-cm increment. The island average for each depth profile (i.e., 0 to 5 cm, 0 to 10 cm, 0 to 15 cm, etc.) was calculated by averaging the results for each profile taken on the island. The results are summarized in Table 3.

Table 3. Average soil concentrations for soil profiles for Bikini and Eneu Islands.

Profile (cm)	Soil concentration (pCi/g dry weight)							
	Bikini Island				Eneu Island			
	^{137}Cs	^{90}Sr	$^{239+240}Pu$	^{241}Am	^{137}Cs	^{90}Sr	$^{239+240}Pu$	^{241}Am
0 to 5	97	103	11	8.7	6.4	4.8	0.82	0.41
0 to 10	90	108	10	8	4.7	4.2	0.73	0.39
0 to 15	79	108	9.7	7.3	4.7	4	0.73	0.42
0 to 25	66	93	8.2	6.4	3.9	4.1	0.75	0.46
0 to 40	54	73	7.1	5.4	3.2	4.5	0.76	0.5

Concentration Ratios

Not all locally grown food products are available at both Bikini and Eneu Islands. The test plots established on Eneu Island have provided data for that island for papaya, banana, sweet potatoes, and squash. Other than these test plots, the only available trees are those planted on the two islands by the TTG in 1970. Coconut trees are available on both islands and breadfruit and *Pandanus* fruit are available in limited quantities on Bikini Island.

Because of the scarcity of some locally grown foods that can be directly analyzed, we have developed concentration ratios between food products and soil (pCi/g wet weight in food per pCi/g dry weight in soil) for each radionuclide. The mean, standard deviation, median, and the high and low values for the concentration ratios developed from samples collected through March 1980 are listed in Tables 4-7 for ^{137}Cs, ^{90}Sr, $^{239+240}Pu$, and ^{241}Am, respectively. The concentration ratios are developed from soil profiles taken to a depth of 40 cm through the root zone of the plants being sampled. This depth is used because we observe that it encompasses most of the active root zone of the subsistence plants we have studied on Enewetak and Bikini Atolls. A report on the root activity of large, mature coconut and banana trees in other tropical regions showed most of the activity in the 0- to 60-cm depth, although root activity did vary with age and species.[14] The report is consistent with our observations of the physical location of the root zone at Enewetak and Bikini Atolls.

Table 4. Concentration ratio of ^{137}Cs estimated over a 0- to 40-cm soil profile for subsistence crops at Bikini and Eneu Islands.

Dietary item	Number of trees or plants	Number of samples	Number of fruits[a]	Concentration ratio[b]	High value	Median	Low value
Drinking coconut meat	82	150	750	6	40	3.7	0.34
Drinking coconut fluid	82	147	735	3	18	1.9	0.1
Copra meat	82	98	490	10	41	6.3	0.82
Sprouting coconut	44	74	370	10	79	5.9	0.92
Breadfruit	10	15	75	0.54	16	0.38	0.12
Pandanus fruit	8	11	22	7.8	34	3.6	0.18
Papaya	48	59	885	2.6	18	0.73	0.036
Squash[c]	13	12	19	2.8	6.1	2.2	0.98
Banana	6	5	50	0.16	0.28	0.14	0.075
Watermelon[c]	17	17	49	1.1	3.3	1.1	0.11

[a] Average number of fruit taken per sample are approximately 5 for coconut and breadfruit, 2 for *Pandanus*, 15 for papaya, 2 for squash, 10 for banana, and 3 for watermelon.

[b] The pCi/g fruit wet weight per pCi/g soil dry weight.

[c] Concentration ratio for a 0- to 5-cm soil profile because of shallow root system.

Table 5. Concentration ratio of ^{90}Sr estimated over a 0- to 40-cm soil profile for subsistence crops at Bikini and Eneu Islands.

Dietary item	Number of trees or plants	Concentration ratio[a]	Standard deviation	High value	Median	Low value
Coconut meat	26	9.8 (-3)[b]	1.2 (-2)	7.3 (-2)	5.1 (-3)	8.6 (-4)
Coconut fluid	17	1.8 (-3)	1.9 (-3)	5.9 (-5)	9 (-4)	7.6 (-3)
Breadfruit	9	0.07	0.058	0.15	5.5 (-3)	5.8 (-3)
Pandanus fruit	3	0.46	0.22	0.69	0.42	0.26
Papaya	15	4.1 (-2)	3.5 (-2)	1.1 (-1)	2.8 (-2)	9.8 (-3)
Squash	6	2.4 (-2)	1.2 (-2)	4 (-2)	2.4 (-2)	8.8 (-3)
Banana	3	9.6 (-3)	5.5 (-3)	1.5 (-2)	7.7 (-3)	5.8 (-3)
Watermelon	8	1.8 (-2)	7.9 (-3)	2.9 (-2)	1.5 (-2)	7.2 (-3)

[a] The pCi/g fruit wet weight per pCi/g soil dry weight.

[b] Values in parentheses indicate powers of ten.

Table 6. Concentration ratio of $^{239+240}Pu$ estimated over a 0- to 40-cm soil profile for subsistence crops at Bikini and Eneu Islands.

Dietary item	Number of trees or plants	Concentration ratio[a]	Standard deviation	High value	Median	Low value
Coconut meat	22	9.7 (-5)[b]	1.3 (-4)	4.8 (-4)	3.1 (-5)	1.7 (-6)
Coconut fluid	11	1.2 (-5)	--	--	--	--
Breadfruit	8	1.5 (-5)	1.6 (-5)	4.7 (-5)	1.2 (-5)	1.6 (-6)
Pandanus fruit	3	4.3 (-5)	4.2 (-5)	8.9 (-5)	3.3 (-5)	6.4 (-6)
Papaya	16	3.6 (-5)	4.8 (-5)	1.8 (-4)	2 (-5)	3.3 (-7)
Squash	5	1.9 (-5)	1.5 (-5)	4 (-5)	1.2 (-5)	3.3 (-6)
Banana	3	2.4 (-5)	3.4 (-5)	6.4 (-5)	7.2 (-6)	8.4 (-7)
Watermelon	8	4 (-5)	3.3 (-5)	8.9 (-5)	3.2 (-5)	7.1 (-6)

[a] The pCi/g fruit wet weight per pCi/g soil dry weight.

[b] Values in parentheses indicate powers of ten.

Table 7. Concentration ratio of ^{241}Am estimated over a 0- to 40-cm soil profile for subsistence crops at Bikini and Eneu Islands.

Dietary item	Number of trees or plants	Concentration ratio[a]	Standard deviation	High value	Median	Low value
Coconut meat	15	1.4 (-4)[b]	2.7 (-4)	1.1 (-3)	3.7 (-5)	4.1 (-6)
Coconut fluid	11	1.1 (-5)	--	--	--	--
Breadfruit	5	1.7 (-5)	2.2 (-5)	5.6 (-5)	6.5 (-6)	2.6 (-6)
Pandanus fruit	2	1.2 (-4)	1.5 (-4)	2.3 (-4)	1.2 (-4)	1 (-5)
Papaya	13	1.4 (-4)	2.8 (-4)	1 (-3)	2.2 (-5)	6.1 (-7)
Banana	2	1.2 (-5)	1.3 (-5)	2.2 (-5)	--	3.1 (-6)
Watermelon	7	2.7 (-5)	2.7 (-5)	7.8 (-5)	2.4 (-5)	2.5 (-6)

[a] The pCi/g fruit wet weight per pCi/g soil dry weight.

[b] Values in parentheses indicate powers of ten.

Food Radionuclide Concentrations

The radionuclide concentrations directly measured in local foods for Bikini and Eneu Islands and used in the dose assessment are listed in Table 8. Because in many cases insufficient food products were available for directly determining the radionuclide concentrations in all locally grown foods at both islands, we have predicted the radionuclide concentrations in those foods for which we do not have direct data for each island by multiplying the average island soil concentrations for the 0- to 40-cm depth for one island by the concentration ratios developed for the 0- to 40-cm profile at the other island (Tables 4-7). These predicted and measured radionuclide concentrations in foods are then used in conjunction with the assumed average diets and dose models to develop the dose assessment for various alternate living patterns.

Table 8. Radionuclide concentration in local food products at Bikini and Eneu Islands.

Dietary item	Concentration (pCi/g wet weight)			
	^{137}Cs	^{90}Sr	$^{239+240}Pu$	^{241}Am
	Bikini Island			
Coconut crabs	48	8.81	6.8 (-3)[a]	3.4 (-3)
Land crabs	48	8.81	6.8 (-3)	3.4 (-3)
Chicken muscle	6.9	0.057	--	--
Chicken liver	6.9	0.057	--	--
Chicken gizzard	6.9	0.057	--	--
Pork muscle	232	1.73	--	--
Pork kidney	216	1.79	--	--
Pork liver	94	0.67	--	--
Pork heart	123	1.04	--	--
Bird muscle	0.055	0.04	3.8 (-4)	1.9 (-4)
Bird viscera	0.4	0.04	--	--
Bird eggs	0.033	0.018	3.8 (-4)	1.9 (-4)
Chicken eggs[b]	6.9	0.057	--	--
Pandanus fruit	199	9.5	1.5 (-4)	2.1 (-4)
Pandanus nuts	199	9.5	1.5 (-4)	2.1 (-4)
Breadfruit	21.6	4.34	8.1 (-5)	5.7 (-5)
Coconut fluid	85	0.0195	6.1 (-6)	5.4 (-6)
Coconut milk	238	0.22	1.1 (-4)	2.4 (-5)
Tuba/Jekero	169	0.22	1.1 (-4)	2.4 (-5)
Drinking coconut meat	193	0.22	1.1 (-4)	2.4 (-5)
Copra meat	238	0.22	1.1 (-4)	2.4 (-5)
Sprouting coconut	260	0.22	1.1 (-4)	2.4 (-5)
Marshallese cake	238	0.22	1.1 (-4)	2.4 (-5)
Papaya	98	1.9	7.7 (-5)	9.8 (-5)
Rainwater	1.9 (-3)	6.1 (-4)	6.3 (-6)	3.2 (-6)
Wellwater	0.43	0.12	4.5 (-5)	2.2 (-5)
Malolo	1.9 (-3)	6.1 (-4)	6.3 (-6)	3.2 (-6)
Coffee/tea	1.9 (-3)	6.1 (-4)	6.3 (-6)	3.2 (-6)

Table 8. (Continued)

Dietary Item	Concentration (pCi/g wet weight)			
	^{137}Cs	^{90}Sr	$^{239+240}Pu$	^{241}Am
	Eneu Island			
Coconut crabs	48	8.81	6.8 (-3)	3.4 (-3)
Land crabs	48	8.81	6.8 (-3)	3.4 (-3)
Chicken muscle[c]	1.7	0.014	--	--
Chicken liver[c]	1.7	0.014	--	--
Chicken gizzard[c]	1.7	0.014	--	--
Pork muscle[c]	52	0.43	--	--
Pork kidney[c]	36	0.3	--	--
Pork liver[c]	25	0.21	--	--
Pork heart[c]	31	0.25	--	--
Bird muscle	0.055	0.04	3.8 (-4)	1.9 (-4)
Bird viscera	0.4	0.04	--	--
Bird eggs[b]	0.033	0.018	3.8 (-4)	1.9 (-4)
Chicken eggs	1.7	0.014	--	--
Coconut fluid	9.8	5.1 (-3)	1.68 (-5)	1.15 (-5)
Coconut milk	37	0.063	1.4 (-4)	1.1 (-4)
Tuba/Jekeru	21	0.063	1.4 (-4)	1.1 (-4)
Drinking coconut meat	19	0.063	1.4 (-4)	1.1 (-4)
Copra meat	37	0.063	1.4 (-4)	1.1 (-4)
Sprouting coconut	40	0.063	1.4 (-4)	1.1 (-4)
Marshallese cake	37	0.063	1.4 (-4)	1.1 (-4)
Papaya	14	0.2	8.6 (-6)	5.7 (-5)
Squash	8.5	0.064	8 (-6)	4 (-6)
Pumpkin	8.5	0.064	8 (-6)	4 (-6)
Banana	0.86	--	--	--
Watermelon	2.6	0.031	1.3 (-5)	4.2 (-6)
Arrowroot	0.93	--	--	--
Rainwater	3.1 (-4)	2.4 (-4)	4.5 (-6)	2.3 (-6)
Wellwater	0.031	0.031	9.2 (-6)	4.6 (-6)
Malolo	3.1 (-4)	2.4 (-4)	4.5 (-6)	2.3 (-6)
Coffee/tea	3.1 (-4)	2.4 (-4)	4.5 (-6)	2.3 (-6)

[a] Values in parentheses indicate powers of ten.

[b] Assumed to be the same as chicken.

[c] Pig and chicken data from Bikini Island.

MARINE FOODS, BIRDS, AND COCONUT CRABS

The radionuclide concentrations in marine fish, shellfish, invertebrates, birds, and coconut crabs are listed in Table 9 along with the sources of data. Some of the data are limited but the radionuclide concentrations in most of the species, which constitute a very small portion of the diet, are quite low. Thus, they have a minimal impact on the overall dose assessment. Other assumptions have been identified in the table footnotes.

DIET

The estimated average diet used in the dose assessment is a very critical parameter; doses will correspond directly with the quantity of locally grown food that is consumed. Therefore, an accurate estimate of the average daily consumption rate of each food item is important.

Because we have been unable to obtain information on the dietary habits of the people who had been living on Bikini Island, the diet used in this dose assessment is that recently developed from the MLSC survey conducted of the Enewetak people on Ujelang Atoll. The field notes from Pritchard, who conducted the survey, are included in Appendix A along with a sample questionnaire. A detailed summary by the Lawrence Livermore National Laboratory (LLNL) of that survey is also included in Appendix A.

There were 144 persons, approximately 25% of the Ujelang population, who were interviewed. Two females failed to complete the dietary questionnaire. The breakdown by age group was as follows:

36 adult males,

36 adult females,

19 children 12 through 17 y of age,

37 children 4 through 11 y of age, and

16 children 0 through 3 y of age.

Some people were away from the atoll during the interview, so selection was limited to those households where several people were available. The households were selected at random from the available pool.

Throughout our discussions of diet and estimated dose, three expressions are used extensively: imports available, imports unavailable, and local foods. Imports-available conditions exist when field ships arrive on schedule and imported and local foods are both available. Imports unavailable indicates a condition where there is an absence of imported foods. Local foods is a LLNL expression for the locally grown foods of the MLSC Ujelang survey. Under normal conditions, imported foods are preferred over local

Table 9. Measured and estimated radionuclide concentrations in marine species and birds and coconut crabs at Bikini Atoll.

Dietary item	Concentration (pCi/g wet weight)			
	^{137}Cs	^{90}Sr	$^{239+240}Pu$	^{241}Am
Fish (reef)[a]	0.16	0.002	3.8×10^{-4}	1.9×10^{-4}
Fish (pelagic)[a]	0.14	0.002	3.8×10^{-4}	1.9×10^{-4}
Shellfish[b]	0.005	0.005	1.7×10^{-3}	0.85×10^{-3}
Clams[b,c]	0.011	0.006	1.4×10^{-3}	0.7×10^{-3}[d]
Birds[b]	0.055	0.04	1.3×10^{-4}[e]	0.65×10^{-4}[e]
Bird eggs[b]	0.033	0.018	1.3×10^{-4}[e]	0.65×10^{-4}[e]
Crabs[b,f]	48	8.81	6.8×10^{-3}	3.4×10^{-3}

[a] Reference 15.

[b] References 16-20.

[c] Includes both muscle tissue and hepatopancreas.

[d] Calculated using the fish $^{239+240}Pu$ to ^{241}Am ratio of two.

[e] Assumed to be the same as fish muscle.

[f] Includes coconut and land crabs, which are assumed to have the same radionuclide concentrations in tissue.

food items. When imports are unavailable, it is assumed that local food consumption increases and that the intake of imported foods would be much more limited. This condition is then projected over a lifetime.

Data on the dietary preferences of the Enewetak people were provided to LLNL in three parts: (1) household survey results for the Ujelang population, (2) individual medical and diet (IMD) survey results for 144 persons, and (3) a memorandum from Pritchard of the MLSC.[21] This memorandum, with minor editing for style but with content unchanged, appears in Appendix A. According to Pritchard, "the household survey met three major needs: it provided in descriptive fashion an account of the eating habits for the entire population of Ujelang; it provided data on certain special diets for certain types of individuals such as pregnant women; and served as a census document for locating individuals for the IMD survey." The completed IMD questionnaires provided, when known, each individual's name, age, sex, height, weight, sickness frequency, prior medical treatment, x-ray history, radiation therapy history, parental data, and preference for various local and imported foods for conditions where imported foods were both available and unavailable. Consumed quantities of each food item preferred were expressed in volume equivalents of a 12-oz beverage can per day, week, and month. Pritchard's memorandum provided insight into such things as the overall survey procedure, the estimated uncertainties in some reported values, the preferences in preparation and consumption of many food items, and the can conversion data for some food items (grams of food per 12-oz can).

We have used the dietary results of the IMD questionnaires to determine the mean intakes in grams per day of local and imported foods when imports are available and unavailable for adult males, adult females, and children in the 0- through 3-, 4- through 11-, and 12- through 17-y age ranges at Bikini Atoll. However, before presenting the results for mean intakes, a brief description of the procedure is in order.

Initially, each questionnaire was examined to determine the total number of preferred individual food items. Once this was done, we established a standard computer-card format for all the food items and then transferred each individual's monthly dietary preferences to cards. Where an individual showed no preference (response) for a specific food item, a blank field appears on the card. In those cases where an individual showed a preference for a specific organ of domestic meat (pork or chicken), they have been so recorded. However, in those cases where more than one organ was preferred, but no relative preference given, we have arbitrarily recorded them under the liver.

Concurrently, we developed the can conversion data necessary to convert the 12-oz cans per month to grams per day. The methods used to determine these conversions were many and varied. In some cases, 12-oz cans were packed with the specific food item and weighed; in others, the weights for canned or packaged foods were used. In still others, such as some marine foods, densities in grams per cubic centimeter were computed and used for the conversion. Some assumptions were also made where a specific food item was unavailable. Tables 10 and 11 summarize the can conversion data developed for the local and imported foods, respectively. In each table, the mean values of specific foods have been grouped under the major categories. We have included the results reported by Pritchard, where appropriate, and have made liberal use of footnotes to clarify the sources of data.

Table 10. Summary of can conversion data for local dietary items for the MLSC survey of Ujelang.

Dietary item	Grams per 12-oz can	Dietary item	Grams per 12-oz can
Fish		Pork muscle (raw)	369[j]
Reef fish	219	Pork kidney (raw)	367[j]
Tuna	290[a]	Pork liver (raw)	409[h]
Mahi Mahi	250[a]	Pork heart	369
Shellfish		Wild birds	
Marine crabs	362[b]	Bird muscle (raw)	369[i]
Lobster	354[c]	Bird viscera (raw)	409[i]
Clams		Eggs	
Clam muscles	368[d]	Bird eggs	364[k]
Trochus	368[e]	Chicken eggs	364
Tridacna muscle	368[e]	Turtle eggs	364[k]
Tridacna viscera	368[e]		
Jedrul	368[e]	Pandanus	
		Pandanus fruit	119 (112)[l]
Crabs		Pandanus nuts	340[m]
Coconut crabs	362[f]		
Land crabs	362[f]	Coconut fluid	
		Coconut juice	355[n]
Octopus	364[g]	Coconut milk	355[n]
		Tuba or Jekeru	355[n]
Turtle	368[g]		
		Coconut meat	
Domestic meat		Young coconut	300[a]
Chicken muscle (raw)	369	Middle-aged coconut	210 (185)[a]
Chicken liver (raw)	409[h]	Old coconut	125[a]
Chicken gizzard (raw)	369[i]	Marshallese cake	54[o]

Table 10. (Continued)

Dietary item	Grams per 12-oz can	Dietary item	Grams per 12-oz can
Papaya	380	Aqueous liquids	
Squash (uncooked)	232	Rainwater	355
Pumpkin (uncooked)	232	Well water	355
Banana	252	Malolo	355[n]
Watermelon	253	Coffee or tea	355[n]
Arrowroot	242 (220)[a]		
Citrus	319		

[a] Weight reported by Pritchard.
[b] Calculated from density of Dungeness crab.
[c] Calculated from density of lobster tail.
[d] Calculated from density of cherrystone clam muscle.
[e] Assumed the same as clam muscle.
[f] Assumed the same as marine crab.
[g] Calculated from density of squid.
[h] Assumed the same as beef liver.
[i] Assumed the same as chicken muscle.
[j] Assumed the same as beef kidney.
[k] Assumed the same as chicken eggs. Value is mean for raw (393 g/can) and scrambled (355 g/can).
[l] Raw Pandanus less fibrous strings.
[m] Assumed the same as roasted peanuts and cashews.
[n] Assumed the same as water.
[o] Quantity of coconut meat in Marshallese cake.

Table 11. Summary of can conversion data for imported dietary items for the MLSC survey at Ujelang.

Dietary item	Grams per 12-oz can	Dietary item	Grams per 12-oz can
Baked bread	130 (90)[a]	Carbonated drinks	355[c]
Fried bread	115 (186)[b]		
Pancakes	166	Canned juices	
Cake	141	Orange juice	355[c]
Rice (cooked)	343	Tomato juice	355[c]
Instant potatoes (cooked)	355	Pineapple juice	355[c]
Sugar	350[c]	Other canned juice	355[c]
Canned meats and poultry		Milk products	
Canned chicken	341[c]	Evaporated milk	355[c]
Corned beef	340[c]	Powdered milk	355[c]
Spam	340[c]	Whole milk	355[c]
		Canned butter	340[e]
Canned fish			
Canned mackerel	340[c]	Onion	235
Canned sardines	339[c]	Canned vegetables	340[c]
Canned tuna	340[c]	Baby food	341[c]
Canned salmon	341[c]	Cocoa	355[c]
Other canned fish	340[c]	Ramen noodles (cooked)	364
		Candy	200
Other meat, fish, or poultry	340[d]		

[a] Weight reported by Pritchard.

[b] Mean weight for two forms of fried bread. Round doughnut holes (151 g/can) and a heavier version (220 g/can). Both of equal popularity.

[c] Weight in grams from grocery store containers.

[d] Assumed the same as canned meat, fish, and poultry.

[e] Weight reported is for lard.

In terms of accuracy, our can conversion data have some limitations. First, we were not able to obtain samples of all foods. Second, our data for fish, shellfish, clams, crabs, octopus, turtle, domestic meat, and wild birds are raw weights, whereas some of these foods are only consumed after some form of cooking. Third, we have assumed an average for raw and scrambled eggs since Pritchard reports that bird eggs are "usually eaten scrambled," chicken eggs are not described, and turtle eggs are "usually eaten raw or scrambled." Fourth, pumpkin (and undoubtedly squash) is consumed cooked rather than uncooked. Fifth, there may be other foods that are consumed in a different form than we reported. Sixth, the differences between the LLNL and MLSC values for a specific food item could reflect differences in food form (e.g., raw or cooked), can packing, or both. To be more precise, the can conversion data would require detailed weighing of each food item in the form consumed by the Enewetak people.

The final step in our procedure was to analyze the local food data with a computer code specifically developed for that purpose. The mean intake, standard deviation, high intake, low intake, and percent responding (i.e., N/N_0 where N is the number responding and N_0 is the total) for the sample were determined for each specific food item and major category identified. Similar methods were used to develop the summary of the imported portion of the diet.

Tables 12 through 16 summarize our dietary-intake results for local foods when imports are available and unavailable for adult males (18 to 80 y); adult females (18 to 78 y); and children in the 0- through 3-, 4- through 11-, and 12- through 17-y age ranges, respectively. Results for imported foods (normal conditions only) are summarized in Tables 17 through 19.

In a summary of a survey conducted during July and August 1967 at Majuro Atoll, the average coconut use was reported to be approximately 0.5 coconut per day per person.[22] This included young drinking coconuts, old nuts used for grated meat and pressed for small volumes of milk, and sprouting nuts used for the sweet, soft core. Recent data from Eneu Island shows that an average drinking coconut contains 325 ml of fluid (standard deviation = 125 ml) so that even if the entire average coconut use of 0.5/d were all drinking nuts, the average intake would be about 160 g/d. This is in agreement with the results from the MLSC survey at Ujelang.

The recent BNL report that became available after ours had essentially been completed discusses dietary habits and living patterns at atolls in the Northern Marshall Islands other than Ujelang and Enewetak.[6] The data were obtained by the authors from personal observations while living with the Marshallese and from answers to questionnaires.

Table 12. Intake in grams per day of local dietary items in the MLSC survey at Ujelang for adult males (18 to 80 y).

	IMPORTS AVAILABLE						IMPORTS UNAVAILABLE					
FOOD	N	MEAN	SIGMA	LOW	HIGH	PROPORTION OF NON ZEROS	N	MEAN	SIGMA	LOW	HIGH	PROPORTION OF NON ZEROS
REEF FISH	36	20.60	15.36	0.00	78.47	0.97	36	40.95	38.26	7.88	219.00	1.00
TUNA	36	15.76	14.97	0.00	62.36	0.81	36	34.73	30.83	4.83	146.00	1.00
MAHI MAHI	36	5.13	9.82	0.00	53.75	0.61	36	13.62	21.12	0.00	107.50	0.78
MARINE CRABS	35	1.01	3.21	0.00	13.03	0.14	35	2.59	6.66	0.00	25.94	0.26
LOBSTER	36	4.85	7.08	0.00	25.37	0.47	36	25.08	40.44	0.00	177.00	0.89
CLAMS	36	4.66	7.28	0.00	26.37	0.44	36	32.94	43.56	0.00	184.00	0.97
TROCHUS	36	0.48	1.87	0.00	10.55	0.14	36	1.00	4.49	0.00	26.37	0.14
TRIDACNA MUSCLE	34	1.76	3.21	0.00	13.25	0.35	35	8.59	17.93	0.00	92.00	0.63
TRIDACNA VISCERA	35	0.86	2.05	0.00	10.55	0.29	35	2.37	5.01	0.00	26.37	0.49
JEDRUL	36	1.68	3.86	0.00	13.25	0.31	36	8.53	18.74	0.00	92.00	0.50
COCONUT CRABS	36	3.10	7.13	0.00	38.91	0.44	36	8.42	11.71	0.00	61.89	0.83
LAND CRABS	36	0.25	1.11	0.00	6.03	0.06	36	5.64	30.16	0.00	181.00	0.11
OCTOPUS	36	2.56	5.20	0.00	26.09	0.56	36	12.10	21.82	0.00	91.00	0.86
TURTLE	36	3.67	6.86	0.00	26.37	0.72	36	7.58	13.02	0.00	62.75	0.94
CHICKEN MUSCLE	36	5.03	9.92	0.00	39.73	0.61	36	9.94	15.66	0.00	52.89	0.83
CHICKEN LIVER	35	1.77	3.65	0.00	14.72	0.49	35	3.90	6.58	0.00	29.31	0.66
CHICKEN GIZZARD	0	NO RESPONSE					1	10.58	0.00	10.58	10.58	1.00
PORK MUSCLE	36	7.76	10.67	0.00	52.89	0.81	36	12.37	18.46	0.00	92.25	0.97
PORK KIDNEY	0	NO RESPONSE					0	NO RESPONSE				
PORK LIVER	36	4.14	6.46	0.00	29.31	0.69	36	5.63	7.63	0.00	29.31	0.83
PORK HEART	0	NO RESPONSE					0	NO RESPONSE				
BIRD MUSCLE	36	6.07	9.47	0.00	26.44	0.42	36	17.18	17.96	0.00	79.33	0.83
BIRD VISCERA	36	2.71	4.91	0.00	14.72	0.33	36	8.25	8.72	0.00	29.31	0.81
BIRD EGGS	36	3.74	7.05	0.00	26.09	0.39	36	8.26	10.09	0.00	26.09	0.72
CHICKEN EGGS	36	3.17	5.81	0.00	26.09	0.44	36	6.06	8.40	0.00	26.09	0.75
TURTLE EGGS	16	2.15	3.36	0.00	12.13	0.76	16	2.24	3.32	0.00	12.13	0.81
PANDANUS FRUIT	36	2.53	3.17	0.00	8.03	0.44	36	27.21	33.69	0.00	112.00	0.97
PANDANUS NUTS	36	0.16	0.94	0.00	5.67	0.03	36	0.64	2.03	0.00	9.75	0.11
BREADFRUIT	36	12.80	12.70	0.00	54.25	0.75	36	57.57	61.41	7.81	217.00	1.00
COCONUT FLUID	36	63.65	82.56	0.00	355.00	0.89	36	130.80	111.50	25.44	355.00	1.00
COCONUT MILK	35	35.22	37.02	0.00	177.50	0.86	35	37.18	35.88	0.00	177.50	0.94
TUBA/JEKERO	36	0.71	4.24	0.00	25.44	0.03	36	0.71	4.24	0.00	25.44	0.03
DRINKING COCONUT MEAT	36	9.98	13.83	0.00	75.00	0.58	36	59.31	60.22	0.00	300.00	0.97
COPRA MEAT	36	6.31	16.62	0.00	92.50	0.36	36	33.36	39.10	0.00	165.00	0.97
SPROUTING COCONUT	36	2.99	4.01	0.00	13.46	0.44	36	32.44	30.89	4.50	125.00	1.00
MARSHALLESE CAKE	36	13.22	13.70	0.45	54.00	1.00	36	0.00	0.00	0.00	0.00	0.00
PAPAYA	36	1.63	5.43	0.00	27.23	0.14	36	6.76	11.18	0.00	38.00	0.36
SQUASH	0	NO RESPONSE					0	NO RESPONSE				
PUMPKIN	23	0.17	0.81	0.00	3.87	0.04	23	0.70	2.01	0.00	8.35	0.13
BANANA	36	0.00	0.00	0.00	0.00	0.00	36	0.00	0.00	0.00	0.00	0.00
WATERMELON	0	NO RESPONSE					0	NO RESPONSE				
ARROWROOT	36	2.29	6.94	0.00	31.53	0.17	36	64.82	75.60	0.00	220.00	0.97
CITRUS	36	0.00	0.00	0.00	0.00	0.00	36	0.00	0.00	0.00	0.00	0.00
RAINWATER	36	358.90	257.50	11.83	1420.00	1.00	35	347.90	258.00	11.83	1420.00	1.00
WELLWATER	35	213.20	213.30	0.00	1065.00	0.89	34	217.50	212.50	0.00	1065.00	0.94
MALOLO	20	132.20	135.80	0.00	355.00	0.85	19	0.00	0.00	0.00	0.00	0.00
COFFEE/TEA	36	275.40	280.70	25.44	1775.00	1.00	35	5.07	30.00	0.00	177.50	0.03
TOTAL	36	1234.26	468.47	333.93	3168.40	1.00	36	1310.53	390.14	379.20	2849.45	1.00

Table 13. Intake in grams per day of local dietary items in the MLSC survey at Ujelang for adult females (18 to 78 y).

	IMPORTS AVAILABLE						IMPORTS UNAVAILABLE					
FOOD	N	MEAN	SIGMA	LOW	HIGH	PROPORTION OF NON ZEROS	N	MEAN	SIGMA	LOW	HIGH	PROPORTION OF NON ZEROS
REEF FISH	34	24.17	22.67	0.00	109.50	0.97	34	43.39	45.21	3.65	219.00	1.00
TUNA	34	13.85	16.73	0.00	83.13	0.74	34	36.02	38.73	4.63	207.60	1.00
MAHI MAHI	33	3.56	5.70	0.00	17.92	0.45	34	10.70	16.16	0.00	71.67	0.59
MARINE CRABS	32	1.65	6.37	0.00	25.94	0.09	32	9.75	33.46	0.00	181.00	0.19
LOBSTER	31	3.68	6.97	0.00	25.37	0.48	31	17.61	21.75	0.00	88.50	0.90
CLAMS	33	4.56	10.39	0.00	52.75	0.45	33	29.05	45.57	0.00	184.00	0.94
TROCHUS	34	0.10	0.53	0.00	3.07	0.09	30	0.12	0.56	0.00	3.07	0.10
TRIDACNA MUSCLE	27	1.67	5.23	0.00	26.37	0.37	27	5.72	11.66	0.00	52.75	0.63
TRIDACNA VISCERA	27	0.23	0.74	0.00	3.07	0.15	27	2.00	4.27	0.00	13.25	0.30
JEDRUL	32	3.08	8.04	0.00	36.80	0.38	32	9.69	18.76	0.00	92.00	0.69
COCONUT CRABS	34	3.13	7.45	0.00	38.96	0.32	34	12.47	31.19	0.00	181.00	0.76
LAND CRABS	34	0.00	0.00	0.00	0.00	0.00	34	0.00	0.00	0.00	0.00	0.00
OCTOPUS	31	4.51	8.33	0.00	26.09	0.45	31	24.51	50.49	0.00	273.00	0.87
TURTLE	31	4.34	9.46	0.00	49.07	0.58	30	8.88	12.02	0.00	49.07	0.93
CHICKEN MUSCLE	34	8.36	32.16	0.00	184.50	0.41	34	15.59	63.22	0.00	369.00	0.79
CHICKEN LIVER	32	4.50	18.21	0.00	102.20	0.31	32	8.84	36.00	0.00	204.50	0.50
CHICKEN GIZZARD	2	1.66	2.00	0.25	3.08	1.00	2	1.66	2.00	0.25	3.08	1.00
PORK MUSCLE	34	5.67	10.05	0.00	52.69	0.74	34	6.96	9.81	0.00	52.69	0.97
PORK KIDNEY	0	NO RESPONSE					0	NO RESPONSE				
PORK LIVER	33	2.60	4.15	0.00	14.72	0.58	33	3.35	4.06	0.00	14.72	0.79
PORK HEART	1	10.56	0.00	10.58	10.58	1.00	1	10.58	0.00	10.58	10.58	1.00
BIRD MUSCLE	34	2.71	5.63	0.00	26.44	0.29	34	13.19	19.13	0.00	92.25	0.88
BIRD VISCERA	32	1.56	3.49	0.00	14.72	0.28	34	4.65	6.42	0.00	29.31	0.76
BIRD EGGS	34	1.54	3.86	0.00	13.10	0.21	33	11.38	16.49	0.00	91.00	0.82
CHICKEN EGGS	34	7.25	31.50	0.00	182.00	0.21	34	20.60	65.06	0.00	364.00	0.59
TURTLE EGGS	7	9.36	11.10	0.00	26.09	0.71	7	117.40	293.40	0.00	782.60	0.71
PANDANUS FRUIT	34	8.66	16.36	0.00	82.13	0.68	34	31.48	32.52	0.00	112.00	0.94
PANDANUS NUTS	34	0.50	1.87	0.00	9.75	0.09	34	1.00	2.63	0.00	12.24	0.15
BREADFRUIT	34	27.16	36.07	0.00	182.30	0.82	34	93.06	94.01	7.23	325.50	1.00
COCONUT FLUID	34	99.05	98.19	0.00	355.00	0.91	34	166.50	161.60	0.00	710.00	0.97
COCONUT MILK	28	51.86	65.81	0.00	254.40	0.93	28	60.91	83.23	0.00	355.00	0.96
TUBA/JEKERO	34	0.00	0.00	0.00	0.00	0.00	34	0.00	0.00	0.00	0.00	0.00
DRINKING COCONUT MEAT	34	31.70	64.69	0.00	300.00	0.56	34	90.36	125.10	0.00	600.00	0.85
COPRA MEAT	34	12.15	26.51	0.00	92.50	0.50	34	35.65	45.63	0.00	185.00	0.97
SPROUTING COCONUT	34	7.79	21.69	0.00	125.00	0.53	34	61.15	110.50	0.00	625.00	0.97
MARSHALLESE CAKE	34	11.66	8.63	0.00	27.00	0.94	34	0.00	0.00	0.00	0.00	0.00
PAPAYA	34	6.59	32.75	0.00	190.00	0.12	34	13.48	66.03	0.00	380.00	0.26
SQUASH	0	NO RESPONSE					0	NO RESPONSE				
PUMPKIN	18	1.24	4.00	0.00	16.86	0.28	18	2.72	6.80	0.00	24.98	0.39
BANANA	34	0.02	0.12	0.00	0.67	0.03	34	0.29	1.56	0.00	9.07	0.06
WATERMELON	0	NO RESPONSE					0	NO RESPONSE				
ARROWROOT	34	3.93	11.97	0.00	63.07	0.18	34	47.44	61.33	0.00	227.30	0.76
CITRUS	34	0.00	0.00	0.00	0.00	0.00	34	0.00	0.00	0.00	0.00	0.00
RAINWATER	34	313.20	189.50	0.00	1065.00	0.97	34	314.70	206.60	0.00	1065.00	0.97
WELLWATER	34	206.70	201.50	0.00	1065.00	0.91	34	215.20	205.90	0.00	1065.00	0.91
MALOLO	14	199.30	106.80	0.00	355.00	0.93	14	0.00	0.00	0.00	0.00	0.00
COFFEE/TEA	34	227.90	114.70	0.00	532.50	0.94	33	0.00	0.00	0.00	0.00	0.00
TOTAL	34	1333.94	358.97	431.55	3182.27	1.00	34	1658.05	523.58	525.04	2783.97	1.00

Table 14. Intake in grams per day of local dietary items in the MLSC survey at Ujelang for children from 0 to 3 y.

	IMPORTS AVAILABLE						IMPORTS UNAVAILABLE					
FOOD	N	MEAN	SIGMA	LOW	HIGH	PROPORTION OF NON ZEROS	N	MEAN	SIGMA	LOW	HIGH	PROPORTION OF NON ZEROS
REEF FISH	16	7.66	6.23	0.00	15.70	0.75	16	16.97	26.09	0.00	109.50	0.81
TUNA	16	9.04	7.18	0.00	20.78	0.75	16	13.73	12.19	0.00	31.42	0.81
MAHI MAHI	16	3.84	6.43	0.00	17.92	0.44	16	5.20	9.32	0.00	27.08	0.44
MARINE CRABS	16	0.00	0.00	0.00	0.00	0.00	16	0.00	0.00	0.00	0.00	0.00
LOBSTER	12	1.33	3.69	0.00	12.74	0.25	12	4.92	7.97	0.00	25.37	0.50
CLAMS	16	1.60	3.57	0.00	13.25	0.25	16	4.46	7.41	0.00	26.37	0.44
TROCHUS	15	0.00	0.00	0.00	0.00	0.00	16	0.00	0.00	0.00	0.00	0.00
TRIDACNA MUSCLE	13	0.49	1.15	0.00	3.07	0.23	13	2.52	7.26	0.00	26.37	0.31
TRIDACNA VISCERA	15	0.01	0.03	0.00	0.12	0.07	15	0.01	0.03	0.00	0.12	0.07
JEDRUL	15	1.25	3.46	0.00	13.25	0.20	15	1.60	3.59	0.00	13.25	0.27
COCONUT CRABS	16	1.98	3.80	0.00	13.03	0.38	16	3.88	6.46	0.00	25.94	0.63
LAND CRABS	16	0.00	0.00	0.00	0.00	0.00	16	0.00	0.00	0.00	0.00	0.00
OCTOPUS	12	1.66	3.02	0.00	10.43	0.58	12	1.66	3.02	0.00	10.43	0.58
TURTLE	12	0.67	1.73	0.00	6.13	0.50	12	0.93	1.85	0.00	6.13	0.58
CHICKEN MUSCLE	16	1.65	3.56	0.00	13.28	0.38	16	2.11	3.66	0.00	13.28	0.63
CHICKEN LIVER	16	1.78	3.93	0.00	14.72	0.38	16	0.91	1.88	0.00	6.82	0.50
CHICKEN GIZZARD	0	NO RESPONSE					1	0.00	0.00	0.00	0.00	0.00
PORK MUSCLE	16	2.58	4.48	0.00	13.28	0.75	16	2.87	4.40	0.00	13.28	0.81
PORK KIDNEY	0	NO RESPONSE					0	NO RESPONSE				
PORK LIVER	15	1.08	3.07	0.00	11.72	0.40	16	1.01	2.98	0.00	11.72	0.38
PORK HEART	0	NO RESPONSE					1	0.00	0.00	0.00	0.00	0.00
BIRD MUSCLE	16	1.15	2.21	0.00	6.15	0.25	16	8.10	9.91	0.00	26.44	0.63
BIRD VISCERA	15	0.50	1.11	0.00	3.41	0.20	16	2.14	3.50	0.00	11.72	0.38
BIRD EGGS	16	0.19	0.76	0.00	3.03	0.06	16	2.81	4.43	0.00	13.10	0.44
CHICKEN EGGS	16	2.02	4.00	0.00	13.10	0.38	16	3.04	4.87	0.00	13.10	0.50
TURTLE EGGS	3	1.01	1.75	0.00	3.03	0.33	3	1.01	1.75	0.00	3.03	0.33
PANDANUS FRUIT	16	9.84	19.27	0.00	56.00	0.56	16	21.92	24.68	0.00	56.00	0.81
PANDANUS NUTS	14	0.35	1.30	0.00	4.87	0.07	15	0.32	1.26	0.00	4.87	0.07
BREADFRUIT	16	9.90	22.14	0.00	91.14	0.63	16	45.90	57.02	0.00	217.00	0.88
COCONUT FLUID	16	46.55	56.56	0.00	177.50	0.81	16	85.00	60.53	11.83	177.50	1.00
COCONUT MILK	12	31.13	35.34	0.00	88.75	0.92	12	30.47	35.63	0.00	88.75	0.92
TUBA/JEKERO	16	0.80	3.20	0.00	12.78	0.06	16	0.80	3.20	0.00	12.78	0.06
DRINKING COCONUT MEAT	16	16.94	39.99	0.00	150.00	0.44	16	60.04	80.43	0.00	300.00	0.75
COPRA MEAT	16	3.40	11.65	0.00	46.25	0.19	16	11.26	17.78	0.00	46.25	0.56
SPROUTING COCONUT	15	14.29	34.50	0.00	125.00	0.40	16	40.21	91.39	0.00	375.00	0.81
MARSHALLESE CAKE	16	4.65	5.01	0.00	13.50	0.81	16	0.00	0.00	0.00	0.00	0.00
PAPAYA	14	0.00	0.00	0.00	0.00	0.00	14	0.00	0.00	0.00	0.00	0.00
SQUASH	0	NO RESPONSE					1	0.00	0.00	0.00	0.00	0.00
PUMPKIN	8	0.04	0.11	0.00	0.31	0.13	8	0.28	0.68	0.00	1.93	0.25
BANANA	15	0.02	0.09	0.00	0.34	0.07	15	0.02	0.09	0.00	0.34	0.07
WATERMELON	0	NO RESPONSE					0	NO RESPONSE				
ARROWROOT	16	0.24	0.92	0.00	3.67	0.13	16	36.45	79.56	0.00	315.30	0.50
CITRUS	15	0.00	0.00	0.00	0.00	0.00	15	0.00	0.00	0.00	0.00	0.00
RAINWATER	16	165.60	71.31	25.44	266.30	1.00	16	165.60	71.31	25.44	266.30	1.00
WELLWATER	16	114.90	70.11	12.78	266.30	1.00	16	116.50	68.20	12.78	266.30	1.00
MALOLO	8	122.40	112.70	0.00	266.30	0.88	6	0.00	0.00	0.00	0.00	0.00
COFFEE/TEA	16	160.50	92.52	0.00	365.00	0.94	16	0.00	0.00	0.00	0.00	0.00
TOTAL	16	743.03	199.53	169.44	1221.51	1.00	16	674.64	203.39	84.49	1676.94	1.00

Table 15. Intake in grams per day of local dietary items in the MLSC survey at Ujelang for children from 4 to 11 y.

FOOD	IMPORTS AVAILABLE N	MEAN	SIGMA	LOW	HIGH	PROPORTION OF NON ZEROS	IMPORTS UNAVAILABLE N	MEAN	SIGMA	LOW	HIGH	PROPORTION OF NON ZEROS
REEF FISH	37	13.61	14.14	0.00	62.78	0.92	37	27.01	24.49	3.65	109.50	1.00
TUNA	37	12.09	9.17	0.00	31.22	0.81	37	26.57	17.97	2.42	72.50	1.00
MAHI MAHI	37	3.76	5.98	0.00	17.92	0.41	37	7.60	8.59	0.00	26.92	0.57
MARINE CRABS	36	0.09	0.50	0.00	3.02	0.06	36	3.33	15.56	0.00	90.50	0.11
LOBSTER	35	4.48	6.92	0.00	25.37	0.54	35	14.56	17.31	0.00	88.50	0.94
CLAMS	37	4.65	7.92	0.00	26.37	0.43	37	25.98	36.31	0.00	184.00	0.92
TROCHUS	36	0.00	0.00	0.00	0.00	0.00	36	0.00	0.00	0.00	0.00	0.00
TRIDACNA MUSCLE	32	1.63	3.91	0.00	13.26	0.31	32	6.36	14.23	0.00	73.60	0.59
TRIDACNA VISCERA	32	0.37	1.30	0.00	5.28	0.13	32	0.56	1.43	0.00	5.28	0.22
JEDRUL	37	3.47	15.17	0.00	92.00	0.32	37	6.86	19.26	0.00	92.00	0.51
COCONUT CRABS	37	2.23	4.27	0.00	13.03	0.49	37	12.31	21.20	0.00	90.50	0.89
LAND CRABS	37	0.00	0.00	0.00	0.00	0.00	37	0.00	0.00	0.00	0.00	0.00
OCTOPUS	33	2.14	4.00	0.00	13.10	0.52	34	16.26	46.28	0.00	273.00	0.88
TURTLE	35	1.54	2.67	0.00	10.55	0.63	35	3.25	4.30	0.00	13.25	0.94
CHICKEN MUSCLE	37	5.49	16.43	0.00	92.25	0.54	37	10.36	31.07	0.00	184.50	0.64
CHICKEN LIVER	37	2.70	9.02	0.00	51.12	0.46	37	5.26	17.26	0.00	102.20	0.62
CHICKEN GIZZARD	0	NO RESPONSE					0	NO RESPONSE				
PORK MUSCLE	37	3.90	5.29	0.00	26.44	0.78	37	5.17	6.12	0.00	26.44	0.95
PORK KIDNEY	0	NO RESPONSE					0	NO RESPONSE				
PORK LIVER	37	1.15	2.34	0.00	11.72	0.43	37	1.33	2.36	0.00	11.72	0.51
PORK HEART	0	NO RESPONSE					0	NO RESPONSE				
BIRD MUSCLE	37	2.62	6.71	0.00	26.44	0.32	37	12.20	18.01	0.00	92.25	0.89
BIRD VISCERA	36	0.70	2.58	0.00	14.72	0.20	37	4.08	5.43	0.00	14.72	0.65
BIRD EGGS	37	0.24	1.01	0.00	6.07	0.16	37	6.90	15.46	0.00	91.00	0.76
CHICKEN EGGS	37	5.12	15.95	0.00	91.00	0.41	37	11.13	32.97	0.00	182.00	0.62
TURTLE EGGS	5	1.26	1.62	0.00	3.03	0.60	4	1.56	1.66	0.00	3.03	0.75
PANDANUS FRUIT	37	4.40	9.37	0.00	56.00	0.62	37	21.86	21.67	1.87	84.00	1.00
PANDANUS NUTS	37	0.83	2.88	0.00	12.24	0.14	37	1.46	3.70	0.00	12.24	0.22
BREADFRUIT	37	9.41	9.38	0.00	54.25	0.81	37	41.63	47.30	7.23	217.00	1.00
COCONUT FLUID	37	44.87	47.94	0.00	177.50	0.84	37	112.90	127.00	5.92	621.20	1.00
COCONUT MILK	31	37.12	46.53	0.00	177.50	0.90	31	45.08	51.62	2.37	177.50	1.00
TUBA/JEKERO	37	0.00	0.00	0.00	0.00	0.00	37	0.00	0.00	0.00	0.00	0.00
DRINKING COCONUT MEAT	37	12.54	27.39	0.00	150.00	0.41	37	47.47	54.66	10.80	225.60	1.00
COPRA MEAT	37	6.12	12.07	0.00	46.25	0.35	37	21.05	24.30	0.00	138.70	0.95
SPROUTING COCONUT	37	7.23	16.63	0.00	94.08	0.51	37	29.61	30.08	4.50	126.00	1.00
MARSHALLESE CAKE	37	11.02	8.69	0.00	27.00	0.97	36	0.00	0.00	0.00	0.00	0.00
PAPAYA	34	5.62	17.41	0.00	95.00	0.21	34	8.45	18.51	0.00	76.00	0.35
SQUASH	0	NO RESPONSE					0	NO RESPONSE				
PUMPKIN	15	0.04	0.16	0.00	0.62	0.07	15	1.84	4.63	0.00	16.63	0.27
BANANA	37	0.00	0.00	0.00	0.00	0.00	37	0.00	0.00	0.00	0.00	0.00
WATERMELON	0	NO RESPONSE					0	NO RESPONSE				
ARROWROOT	37	0.10	0.60	0.00	3.67	0.03	37	25.40	42.44	0.00	220.00	0.76
CITRUS	37	0.00	0.00	0.00	0.00	0.00	37	0.00	0.00	0.00	0.00	0.00
RAINWATER	37	204.00	97.48	5.92	532.50	1.00	37	211.80	97.47	25.44	532.50	1.00
WELLWATER	37	136.60	97.39	0.00	532.50	0.92	37	136.90	101.00	0.00	532.50	0.89
MALOLO	11	191.40	105.50	26.44	355.00	1.00	11	0.00	0.00	0.00	0.00	0.00
COFFEE/TEA	37	136.80	79.72	0.00	355.00	0.97	36	0.00	0.00	0.00	0.00	0.00
TOTAL	37	883.62	209.97	360.98	1539.86	1.00	37	914.31	238.94	396.95	2717.05	1.00

Table 16. Intake in grams per day of local dietary items in the MLSC survey at Ujelang for children from 12 to 17 y.

	IMPORTS AVAILABLE						IMPORTS UNAVAILABLE					
FOOD	N	MEAN	SIGMA	LOW	HIGH	PROPORTION OF NON ZEROS	N	MEAN	SIGMA	LOW	HIGH	PROPORTION OF NON ZEROS
REEF FISH	19	15.62	11.73	0.00	47.09	0.95	19	29.28	27.87	7.30	109.50	1.00
TUNA	19	15.03	12.19	0.00	41.57	0.95	19	35.78	49.14	0.00	217.50	0.95
MAHI MAHI	19	5.44	8.04	0.00	35.83	0.79	19	15.79	42.43	0.00	187.50	0.79
MARINE CRABS	18	0.40	0.88	0.00	3.02	0.33	18	0.70	1.54	0.00	6.03	0.39
LOBSTER	18	2.66	5.92	0.00	25.37	0.50	18	7.09	11.67	0.00	50.74	0.89
CLAMS	19	8.12	12.50	0.00	52.75	0.79	19	24.36	44.91	0.49	184.00	1.00
TROCHUS	19	0.35	1.40	0.00	6.13	0.16	19	4.87	21.10	0.00	92.00	0.16
TRIDACNA MUSCLE	15	1.09	1.87	0.00	6.13	0.33	15	2.88	6.75	0.00	26.37	0.53
TRIDACNA VISCERA	14	0.44	1.64	0.00	6.13	0.07	14	0.47	1.63	0.00	6.13	0.21
JEDRUL	19	1.47	2.13	0.00	6.13	0.42	19	11.73	41.63	0.00	184.00	0.58
COCONUT CRABS	19	3.61	6.50	0.00	25.94	0.47	19	29.98	62.60	0.00	271.50	0.89
LAND CRABS	19	0.16	0.69	0.00	3.02	0.05	19	0.16	0.69	0.00	3.02	0.05
OCTOPUS	19	6.17	10.55	0.00	39.43	0.53	19	24.20	44.91	0.00	182.00	0.89
TURTLE	.18	2.77	6.24	0.00	26.37	0.56	18	5.36	12.18	0.00	52.75	0.89
CHICKEN MUSCLE	19	5.79	12.28	0.00	39.73	0.63	19	13.31	17.14	0.00	52.89	0.89
CHICKEN LIVER	17	2.57	4.75	0.00	14.72	0.65	16	3.14	4.91	0.00	14.72	0.75
CHICKEN GIZZARD	2	0.12	0.17	0.00	0.25	0.50	2	13.35	18.53	0.26	26.44	1.00
PORK MUSCLE	19	3.52	3.42	0.00	12.30	0.84	19	5.63	6.22	0.25	26.44	1.00
PORK KIDNEY	0	NO RESPONSE					0	NO RESPONSE				
PORK LIVER	18	2.71	3.57	0.00	14.72	0.78	18	2.90	3.69	0.00	14.72	0.78
PORK HEART	0	NO RESPONSE					0	NO RESPONSE				
BIRD MUSCLE	19	6.51	8.00	0.00	26.44	0.63	19	12.03	14.44	0.00	52.89	0.79
BIRD VISCERA	19	3.38	4.76	0.00	14.72	0.53	19	4.20	4.89	0.00	14.72	0.63
BIRD EGGS	19	6.42	10.65	0.00	36.40	0.63	19	11.08	20.39	0.00	72.80	0.74
CHICKEN EGGS	19	3.03	6.46	0.00	26.09	0.42	19	14.91	41.23	0.00	182.00	0.68
TURTLE EGGS	10	1.87	2.90	0.00	9.10	0.60	10	3.39	3.58	0.00	9.10	0.80
PANDANUS FRUIT	19	6.12	10.96	0.00	48.16	0.68	19	20.89	23.46	4.03	96.32	1.00
PANDANUS NUTS	19	0.58	2.23	0.00	9.75	0.16	19	1.05	3.07	0.00	9.75	0.16
BREADFRUIT	19	17.75	27.22	0.00	108.50	0.74	19	48.47	40.76	0.00	124.40	0.95
COCONUT FLUID	18	64.33	89.56	0.00	355.00	0.89	18	120.20	165.50	5.92	710.00	1.00
COCONUT MILK	15	57.20	54.88	12.78	177.50	1.00	15	56.51	56.31	0.00	177.50	0.93
TUBA/JEKERO	19	0.00	0.00	0.00	0.00	0.00	19	0.00	0.00	0.00	0.00	0.00
DRINKING COCONUT MEAT	19	26.25	68.34	0.00	300.00	0.74	19	66.63	72.53	10.80	300.00	1.00
COPRA MEAT	19	15.33	19.21	0.00	46.25	0.63	19	35.87	28.98	6.66	92.50	1.00
SPROUTING COCONUT	19	5.01	9.47	0.00	31.25	0.53	19	30.47	30.13	4.17	125.00	1.00
MARSHALLESE CAKE	19	7.65	6.12	1.94	27.00	1.00	18	0.00	0.00	0.00	0.00	0.00
PAPAYA	19	0.00	0.00	0.00	0.00	0.00	19	3.93	8.81	0.00	27.23	0.32
SQUASH	0	NO RESPONSE					0	NO RESPONSE				
PUMPKIN	11	4.01	8.69	0.00	25.62	0.27	11	7.00	12.13	0.00	33.25	0.45
BANANA	19	0.00	0.00	0.00	0.00	0.00	19	0.00	0.00	0.00	0.00	0.00
WATERMELON	0	NO RESPONSE					0	NO RESPONSE				
ARROWROOT	19	0.00	0.00	0.00	0.00	0.00	19	32.73	33.01	0.00	110.00	0.95
CITRUS	19	0.00	0.00	0.00	0.00	0.00	19	0.00	0.00	0.00	0.00	0.00
RAINWATER	19	205.50	93.80	88.75	355.00	1.00	19	214.90	90.29	88.75	355.00	1.00
WELLWATER	19	139.20	69.07	71.00	355.00	1.00	19	153.20	66.21	71.00	355.00	1.00
MALOLO	11	105.90	84.54	0.00	266.30	0.91	10	0.00	0.00	0.00	0.00	0.00
COFFEE/TEA	19	169.50	156.10	0.00	710.00	0.95	16	0.18	0.74	0.00	2.96	0.06
TOTAL	19	943.45	261.84	456.88	1696.61	1.00	19	1067.59	268.68	439.48	2133.95	1.00

Table 17. Intake in grams per day of imported dietary items in the MLSC survey at Ujelang for adult males (18 to 80 y) and females (18 to 78 y).

	MALES FROM 18-80 YEARS						FEMALES FROM 18-78 YEARS					
FOOD	N	MEAN	SIGMA	LOW	HIGH	PROPORTION OF NON ZEROS	N	MEAN	SIGMA	LOW	HIGH	PROPORTION OF NON ZEROS
BAKED BREAD	36	31.85	33.40	1.50	180.00	1.00	34	30.28	33.47	3.24	180.00	1.00
FRIED BREAD	36	62.79	67.88	6.70	372.00	1.00	34	71.99	55.75	6.70	186.00	1.00
PANCAKES	36	47.97	38.89	0.00	166.00	0.97	34	59.52	49.87	5.98	166.00	1.00
CAKE	36	2.44	6.43	0.00	30.31	0.58	34	2.64	3.18	0.00	10.10	0.85
RICE	36	240.60	123.50	36.93	514.50	1.00	34	233.50	130.70	36.93	686.00	1.00
INSTANT MASHED POTATOES	36	67.68	102.80	0.00	355.00	0.72	32	128.80	133.00	0.00	443.70	0.94
SUGAR	36	73.07	29.23	2.83	146.20	1.00	34	65.17	35.18	12.24	170.00	1.00
CANNED CHICKEN	36	5.03	8.52	0.00	24.44	0.47	34	12.97	30.92	0.00	170.50	0.47
CORNED BEEF	36	61.48	57.21	12.24	170.00	1.00	34	78.67	75.45	0.00	243.70	0.97
SPAM	36	35.99	41.31	0.00	170.00	0.89	34	54.99	72.31	2.83	340.00	1.00
CANNED MACKERAL	36	26.69	34.68	0.00	170.00	0.72	34	43.99	69.76	0.00	243.70	0.76
CANNED SARDINES	36	24.72	34.18	0.00	169.50	0.75	34	42.63	62.25	0.00	242.90	0.85
CANNED TUNA	36	45.67	60.96	0.00	170.00	0.94	34	58.99	60.35	0.00	170.00	0.97
CANNED SALMON	0	NO RESPONSE					0	NO RESPONSE				
OTHER CANNED FISH	0	NO RESPONSE					0	NO RESPONSE				
OTHER MEAT, FISH, OR POULTRY	0	NO RESPONSE					0	NO RESPONSE				
CARBONATED DRINKS	36	360.70	224.30	60.88	1066.00	1.00	34	337.90	206.40	60.88	1066.00	1.00
ORANGE JUICE	36	105.00	123.80	0.00	355.00	0.75	34	187.80	166.00	0.00	710.00	0.91
TOMATOE JUICE	36	64.86	106.60	0.00	355.00	0.47	33	99.54	129.30	0.00	355.00	0.58
PINEAPPLE JUICE	9	72.42	137.00	0.00	355.00	0.56	4	177.50	205.00	0.00	355.00	0.50
OTHER CANNED JUICE	1	355.00	0.00	355.00	355.00	1.00	1	25.44	0.00	25.44	25.44	1.00
EVAPORATED MILK	36	158.10	102.00	0.00	355.00	0.92	34	201.10	156.60	0.00	710.00	0.97
POWDERED MILK	36	52.03	79.47	0.00	266.30	0.44	34	72.91	120.40	0.00	355.00	0.35
WHOLE MILK	33	0.00	0.00	0.00	0.00	0.00	33	0.00	0.00	0.00	0.00	0.00
CANNED BUTTER	0	NO RESPONSE					1	0.00	0.00	0.00	0.00	0.00
ONION	1	0.00	0.00	0.00	0.00	0.00	2	0.00	0.00	0.00	0.00	0.00
CANNED VEGETABLES	1	0.00	0.00	0.00	0.00	0.00	0	NO RESPONSE				
BABY FOOD	0	NO RESPONSE					0	NO RESPONSE				
COCOA	0	NO RESPONSE					1	177.50	0.00	177.50	177.50	1.00
RAMEN NOODLES	0	NO RESPONSE					1	6.07	0.00	6.07	6.07	1.00
CANDY	0	NO RESPONSE					0	NO RESPONSE				
TOTAL	36	1894.06	395.52	627.10	2720.47	1.00	34	2167.79	483.35	457.69	3136.54	1.00

Table 18. Intake in grams per day of imported dietary items in the MLSC survey at Ujelang for children from 0 to 3 y and from 4 to 11 y.

	CHILDREN FROM 0-3 YEARS						CHILDREN FROM 4-11 YEARS					
FOOD	N	MEAN	SIGMA	LOW	HIGH	PROPORTION OF NON ZEROS	N	MEAN	SIGMA	LOW	HIGH	PROPORTION OF NON ZEROS
BAKED BREAD	16	10.47	11.14	0.75	46.00	1.00	37	21.06	16.83	2.25	67.50	1.00
FRIED BREAD	16	26.20	30.66	0.00	93.31	0.81	37	43.46	29.00	6.70	93.00	1.00
PANCAKES	16	25.24	30.91	0.00	83.28	0.81	37	38.36	27.68	4.76	83.00	1.00
CAKE	16	1.54	2.86	0.00	10.10	0.56	37	1.23	2.36	0.00	10.10	0.51
RICE	16	96.99	89.79	0.00	343.00	0.88	37	153.70	84.17	24.58	343.00	1.00
INSTANT MASHED POTATOES	14	48.97	37.44	0.00	88.75	0.93	37	80.34	92.06	0.00	355.00	0.86
SUGAR	16	44.92	34.00	2.83	85.00	1.00	37	56.68	27.69	5.67	85.00	1.00
CANNED CHICKEN	16	9.13	21.42	0.00	86.25	0.56	37	7.42	15.99	0.00	86.25	0.43
CORNED BEEF	16	21.67	28.08	0.00	85.00	0.81	37	56.30	53.38	0.45	243.70	1.00
SPAM	16	19.10	29.83	0.00	97.47	0.75	37	32.17	28.84	0.00	85.00	0.89
CANNED MACKERAL	16	14.70	21.88	0.00	85.00	0.75	36	32.10	35.13	0.00	170.00	0.92
CANNED SARDINES	16	11.76	21.43	0.00	84.75	0.63	37	29.73	36.12	0.00	169.50	0.86
CANNED TUNA	16	16.95	22.61	0.00	85.00	0.75	37	38.51	35.76	5.67	170.00	1.00
CANNED SALMON	2	0.11	0.16	0.00	0.23	0.50	0	NO RESPONSE				
OTHER CANNED FISH	0	NO RESPONSE					2	0.00	0.00	0.00	0.00	0.00
OTHER MEAT, FISH, OR POULTRY	1	0.00	0.00	0.00	0.00	0.00	2	48.73	34.46	24.37	73.10	1.00
CARBONATED DRINKS	16	171.30	118.50	0.00	356.00	0.88	37	226.50	120.70	50.88	632.50	1.00
ORANGE JUICE	16	68.06	85.38	0.00	266.30	0.81	37	100.10	96.86	0.00	355.00	0.84
TOMATOE JUICE	16	15.63	44.07	0.00	177.50	0.31	37	45.71	69.06	0.00	266.30	0.54
PINEAPPLE JUICE	0	NO RESPONSE					3	147.90	135.60	0.00	266.30	0.67
OTHER CANNED JUICE	4	3.20	6.39	0.00	12.78	0.25	1	0.95	0.00	0.95	0.95	1.00
EVAPORATED MILK	16	103.40	101.70	5.92	355.00	1.00	37	136.80	97.26	12.78	355.00	1.00
POWDERED MILK	16	19.72	47.40	0.00	177.50	0.44	37	61.14	82.36	0.00	266.30	0.61
WHOLE MILK	14	0.00	0.00	0.00	0.00	0.00	36	0.00	0.00	0.00	0.00	0.00
CANNED BUTTER	0	NO RESPONSE					0	NO RESPONSE				
ONION	0	NO RESPONSE					1	0.06	0.00	0.06	0.06	1.00
CANNED VEGETABLES	1	24.37	0.00	24.37	24.37	1.00	0	NO RESPONSE				
BABY FOOD	1	68.20	0.00	68.20	68.20	1.00	0	NO RESPONSE				
COCOA	0	NO RESPONSE					1	0.00	0.00	0.00	0.00	0.00
RAMEN NOODLES	0	NO RESPONSE					0	NO RESPONSE				
CANDY	1	0.53	0.00	0.53	0.53	1.00	1	0.53	0.00	0.53	0.53	1.00
TOTAL	16	822.16	226.34	203.29	1443.03	1.00	37	1358.49	301.51	373.95	2547.58	1.00

Table 19. Intake in grams per day of imported dietary items in the MLSC survey at Ujelang for children from 12 to 17 y.

FOOD	N	MEAN	SIGMA	LOW	HIGH	PROPORTION OF NON ZEROS
BAKED BREAD	19	23.53	23.27	3.24	90.00	1.00
FRIED BREAD	19	52.83	36.79	13.33	139.50	1.00
PANCAKES	19	43.72	48.92	0.00	166.00	0.95
CAKE	19	1.88	2.55	0.00	10.10	0.63
RICE	19	210.80	98.28	61.51	343.00	1.00
INSTANT MASHED POTATOES	19	134.70	159.30	11.83	710.00	1.00
SUGAR	19	67.55	27.48	5.67	85.00	1.00
CANNED CHICKEN	19	5.36	12.03	0.00	48.88	0.42
CORNED BEEF	19	72.01	51.57	12.13	170.00	1.00
SPAM	19	46.09	38.61	12.24	170.00	1.00
CANNED MACKERAL	19	34.45	40.93	0.00	170.00	0.89
CANNED SARDINES	19	41.79	42.77	0.00	169.50	0.89
CANNED TUNA	19	48.64	39.53	12.24	170.00	1.00
CANNED SALMON	0	NO RESPONSE				
OTHER CANNED FISH	0	NO RESPONSE				
OTHER MEAT, FISH, OR POULTRY	0	NO RESPONSE				
CARBONATED DRINKS	19	288.30	101.20	25.44	355.00	1.00
ORANGE JUICE	19	118.00	103.70	0.00	355.00	0.89
TOMATOE JUICE	19	69.54	112.10	0.00	355.00	0.42
PINEAPPLE JUICE	4	155.30	151.60	0.00	355.00	0.75
OTHER CANNED JUICE	0	NO RESPONSE				
EVAPORATED MILK	19	154.10	97.41	0.00	355.00	0.89
POWDERED MILK	19	93.42	86.12	0.00	286.30	0.83
WHOLE MILK	18	0.00	0.00	0.00	0.00	0.00
CANNED BUTTER	0	NO RESPONSE				
ONION	1	0.00	0.00	0.00	0.00	0.00
CANNED VEGETABLES	0	NO RESPONSE				
BABY FOOD	0	NO RESPONSE				
COCOA	0	NO RESPONSE				
RAMEN NOODLES	1	6.07	0.00	6.07	6.07	1.00
CANDY	0	NO RESPONSE				
TOTAL	19	1665.87	350.57	1108.64	2720.91	1.00

The observations and questionnaires were directed more toward estimating the food prepared for a family rather than the amount of food actually consumed. Because food is shared and some food prepared is fed to pigs or chickens, these two are not necessarily the same. In the draft report the authors state:

> This attempt then to seek estimates from the islanders themselves concerning the actual amounts of local foods in the contemporary diet should be used not as an answer to the question of what constitutes the "typical average" but rather as a feasibility study on the possibility of obtaining the desired information in this way. We feel the averages which we obtained from the interview study are for one reason or another consistently overestimated and should be considered maximum estimates or overestimates until such time as further study proves them accurate or (more likely) provides average factors for food sharing and wasting which can be folded into the study to provide more accurate, reduced estimates (Ref. 6).*

The diet patterns are divided into three categories representing three types of communities.

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* Underlined for emphasis.

Community A

(a) Maximum availability of local foods.

(b) Highly depressed local economy--living within income provided by selling copra.

(c) Low population.

(d) Little or no ability to buy imported food.

Community B

(a) Low availability of local foods except fish, which can constitute as much as 33% of the total diet, because of excellent fishing in the area.

(b) Overpopulated--resulting in low availability of local foods.

(c) Good supply of imported foods (supply boat comes in every 2 to 3 wk) and readily available jobs.

Community C

(a) Low availability of local foods, even fishing is poor.

(b) Large government food program.

(c) Overpopulated.

(d) Good supply of imported foods and availability of cash to buy them.

Bikini Atoll tends to fall in the B and C categories of this BNL report. We therefore compare the results of the BNL study for categories B and C with the results from the MLSC Ujelang survey, which we used as the basis for the calculations in our report, in Table 20.

Considering the fact that the MLSC Ujelang survey was conducted in an attempt to ascertain individual consumption and the BNL survey was conducted to ascertain food prepared for a family, the results of the two surveys do for the most part reinforce each other; especially when the BNL survey admittedly probably overestimated the actual food consumed.

The largest discrepancy between the two surveys is for coconut fluid. The range in the MLSC Ujelang survey was 142 to 217 g/d for the average intake. The range in the BNL survey for the average prepared for a household was 430 to 521 g/d. The prepared coconut meat in the BNL survey was 40 to 50% higher than that consumed according to the MLSC Ujelang survey. Pandanus fruit prepared was nearly double the consumption figure.

Fish consumption in the MLSC Ujelang survey is within the range observed by BNL. Intake of shellfish, clams, coconut crabs, domestic meat, wild birds, breadfruit, and arrowroot is greater in the MLSC Ujelang survey than in the BNL survey. The intake of squash and papaya is very similar in the two reports.

Table 20. Diet comparison of the maximum diet from the MLSC survey at Ujelang and the BNL study at Rongelap and Utirik.

Dietary category	Intake for adult female, MLSC Ujelang survey: Imports available (g/d)	Imports unavailable (g/d)	Intake from BNL Marshall Islands survey[a] (g/d)
Fish	42	90	84 to 194
Shellfish[b]	5.1	25	0.14 to 0.4
Clams	8.9	44	5 to 15
Coconut crabs[c]	3.1	13	1 to 2
Domestic meat[d]	21	35	0.7 to 4.4
Wild birds	4	18	0.6 to 9
Eggs[e]	11	56	2.4
Pandanus	9	33	64 to 96
Breadfruit	27	93	36 to 53
Coconut fluid	142	217	430 to 521
Coconut meat	63	187	268 to 280
Squash (pumpkin)	1.2	2.7	0 to 5
Arrowroot	3.9	47	0
Papaya	7	14	0 to 12
Banana	0.02	0.3	17 to 19

[a] Reference 6.
[b] Marine crab and lobster.
[c] Includes land crabs.
[d] Pork and chicken.
[e] Bird, chicken, and turtle.

In evaluating all available data on dietary habits in the Marshall Islands there are a few general conclusions to be drawn.

(1) The dietary intake used here is consistent with other published observations.
(2) The dietary habits of a people are atoll specific and one should not arbitrarily generalize from one atoll to another.
(3) There is still some uncertainty as to what an average diet really is at any atoll.

(4) Many factors can affect the average diet over any specific year.

(5) Further atoll-specific dietary studies are needed to improve the precision of the dose assessments.

The diet established by LLNL that was used in previous assessments[5,23] was developed from our observations and published reports in the literature.[24] Because there were no direct surveys of the people in recent years, this diet was designed to be conservative; that is, it was preferable to overestimate rather than underestimate the intake. The recent MLSC Ujelang and BNL surveys indicate that the earlier intakes were higher than the MLSC survey but less than the BNL estimates.

LIVING PATTERNS

Doses have been estimated for two major living patterns and two variations thereof.

(1) Bikini Island as the residence island with 100% of the time spent on the island and all local foods from Bikini Island.

(2) Eneu Island as the residence island with 100% of the time spent on the island and all local foods from Eneu Island.

(3) Eneu Island as the residence island with 90% of the time spent on Eneu Island and 10% of the time spent on Bikini Island and all local foods from Eneu Island.

(4) Bikini and Eneu Islands as the residence islands with 50% of the time spent on each island and 50% of the diet from each island.

The predicted doses for the above living patterns are calculated for imported foods being both available and unavailable.

DOSE CALCULATIONS

BODY AND ORGAN WEIGHTS

Data from BNL have been summarized to determine the body weight of the Marshallese people.[25,26] The average body weights of adult males are listed in Table 21. The average adult male body weight is 72 kg for Bikini, 71 kg for Enewetak, 61 kg for Rongelap, and 70 kg for Utirik; this is very near the 70-kg value of reference man.[9] As a result we have used 70 kg as the average body weight in our dose calculations. The lower body weight for Rongelap could be because of age distribution and health-related factors. The average body weight for 113 adult females in the Enewetak population is 61 kg; it is 67 kg for 30 Utirik females and 63 kg for 36 Rongelap females.[25]

Table 21. Body weights of Marshallese adult males in kilograms.

Atoll	Number	Mean	Standard deviation	Mininum	Maximum
Utirik[a]	9	69	12.9	59.5	92.7
Bikini[b]	18	71.9	12.4	50	100.5
Rongelap[a]	22	61.2[a]	9.2	46.4	86.8
Enewetak[b]	130	71	14	37	126
TOTAL	179	69.8[c]	--	37	126

[a] Reference 26.

[b] Reference 25.

[c] Weighted mean.

DIET

The maximum diet determined for adults from the MLSC Ujelang survey was for adult females (Table 13), and these data are used in our dose calculations. When the daily food intakes in gram per day are combined with the radionuclide concentrations in the food products (Table 8), the average daily intake of ^{137}Cs for Bikini Island is 41,170 pCi/d when imported foods are available and 85,170 pCi/d when imported foods are unavailable. For Eneu Island when imports are available the intake of ^{137}Cs is 5,842 pCi/d and is 11,670 pCi/d when imports are unavailable.

The corresponding intakes of ^{90}Sr for imports available and unavailable are 325 and 970 pCi/d, respectively, for Bikini Island and 64.2 and 197 pCi/d, respectively, for Eneu Island.

STRONTIUM-90 METHODOLOGY

Bone-marrow doses and dose rates are calculated in two steps. First, the model of Bennett[27-29] is used to correlate the ^{90}Sr concentrations in diet with that in mineral bone. Second, the dosimetric model developed by Spiers[30] is used to calculate the bone-marrow dose rate from the concentration in mineral bone.

Bennett's empirical model is developed from ^{90}Sr concentrations found in foods and autopsy bone samples from New York and San Francisco. The concentrations in the diet are the concentrations expected to result from worldwide fallout. The model is thought to adequately reflect the ^{90}Sr concentration in bone, which corresponds to the ^{90}Sr concentration in the Marshallese diet; it uses as input the actual dietary ^{90}Sr concentration and the output is the actual ^{90}Sr concentration in mineral bone determined from analysis of autopsy samples. It also includes age-dependent variations that allow us to make dose estimates for children as well as adults. An estimate of the calcium content of the normal Marshallese diet is listed in Table 22; the average intake is 0.8 g/d, which is very similar to the 0.9 g/d estimated for U.S. diets. The model is rather insensitive to calcium intake unless it greatly exceeds 1 g/d or is less than 0.3 g/d.[31] Therefore, the similar intake of calcium of the overall Marshallese and U.S. diets would indicate no major problems in applying the ^{90}Sr model to the Marshallese population.

Using Spiers' model we calculate the dose rate D_o to a small, tissue-filled cavity in bone from the ^{90}Sr concentration in mineral bone. Then from geometrical considerations, the dose rates to the bone marrow D_m and endosteal cells D_s are calculated using conversion factors $D_m/D_o = 0.32$ and $D_s/D_o = 0.43$, respectively. These factors are quoted by the United Nations Scientific Committee on the Effects of Atomic Radiation[32] and are equivalent to a bone-marrow dose rate of 1.4 mrad/y per pCi ^{90}Sr/g calcium and an endosteal cell dose rate of 1.9 mrad/y per pCi ^{90}Sr/g calcium. These dose rates are determined directly and not by comparison to radium. Therefore rads are equivalent to rems. Because bone marrow is considered a blood-forming organ (annual dose limit equals 500 mrem/y) and endosteal cells are in the other-organ category (annual dose limit equals 1500 mrem/y), the bone marrow is the more sensitive organ in bone for ^{90}Sr.[33]

CESIUM-137 AND COBALT-60 METHODOLOGY

For ^{137}Cs and ^{60}Co, the methods of the ICRP[11,34,35] and the National Council on Radiation Protection and Measurements (NCRP)[36] as developed by Killough and Rohwer in their INDOS code[37] are used for the dose calculations. This code is used as published; however, the output is modified to show the body burdens for each year. For ^{137}Cs, which is of major importance in the Marshall Islands, the model for adults consists of two compartments with removal half-times of 2 and 110 d, with 10% of the intake going to the 2-d compartment and 90% to the 110-d compartment. These data are consistent with preliminary data obtained by BNL on the half-time of the long-term compartment in the Marshallese.[38] The average results for 10 Marshallese males showed a mean of 114 d (range: 76 to 178 d) for the long-term compartment. For 21 females the mean value is 83 d (range: 63 to 126 d). The gut transfer coefficient for ^{137}Cs is 1.

Table 22. Average daily calcium intake for the Marshallese female diet for normal conditions.

Dietary item	Calcium (mg per 100 g[a])	Intake (g/d)	Calcium (mg/d)
Fish	20	187	37
Turtle	110	4.3	5
Meat	12	168	20
Breadfruit	22	27	5.9
Pandanus	10	9.2	0.92
Banana	7	0.02	0.001
Lobster	45	5.1	2.3
Milk	120	274	328
Coconut meat	.10	63	63
Coconut fluid	30	142	43
Bread	84[b]	102	86
Rice	10	234	23
Carbonated drink	8[b]	338	27
Canned juices	8[b]	306	25
Clams	100	8.9	8.9
Crabs	45	3.1	1.4
Potatoes	10	127	13
Eggs	55	11	6.1
Pancakes	215	60	129
TOTAL	--	--	824

[a] Reference 39.

[b] Reference 40.

The half-time of ^{137}Cs in children is determined in two stages. The equation used to determine the half-time of ^{137}Cs, developed by Fisher and Snyder at Oak Ridge National Laboratory, is $T_{1/2}$ = 1.63 M where M is the body mass in kilograms.[41] The constant of 1.63 is adjusted from the original 1.43 to account for the now accepted, 115-d long-term compartment. The M as a function of age is determined using equations given by Spiers.[30] When the Snyder and Spiers equations are combined, the half-time as a function of age can be determined. The average half-time using the above approach for ages 5 through 10 is about 42 d. Data from BNL whole-body counting for 14 Marshallese children in this age bracket is 43 d. For ages 11 to 15, the Snyder-Spiers method gives an average half-time of about 70 d while the BNL data for nine adolescents in this age bracket is 69 d.[25]

The model for ^{60}Co is a three-compartment model with half-times of 6, 60, and 800 d with 60, 20, and 20% of the intake, respectively.[11]

TRANSURANIC RADIONUCLIDES METHODOLOGY

Inhalation

The inhalation model used for the various isotopes of plutonium and for ^{241}Am is that of the ICRP Task Group.[10,42] Parameters for the lung model are also those of the ICRP--the gut-to-blood transfer for plutonium isotopes is 1×10^{-4} and for ^{241}Am it is 5×10^{-4}.[11] Both ^{241}Am and plutonium are assumed to be class-W compounds.

Ingestion

For the ingestion pathway, the gut transfer coefficients are, as stated above, 1×10^{-4} for plutonium and 5×10^{-4} for ^{241}Am. The critical organs are bone and liver with 100-y biological half-lives for plutonium and ^{241}Am in bone and 40 y in liver. Of the plutonium and ^{241}Am transferred to blood, 45% is assumed to reach the bone and 45% is assumed to reach the liver. The remaining 10% is distributed among other organs.

RESULTS

Here we present the predicted maximum annual dose rates and the 30- and 50-y integral doses for the different living patterns and options; we assume for purposes of discussion that residence will begin in January 1981. The doses are calculated using the average dietary intake, radionuclide concentration, radionuclide fraction absorbed into the body from that ingested, biological residence times, and external dose rate. The maximum annual dose rate for the whole body is defined as the dose rate in that year after the Marshallese return when the sum of the whole-body ingestion dose from ^{137}Cs and the external gamma dose is a maximum. For bone marrow the maximum occurs when the bone-marrow ingestion dose from ^{137}Cs and ^{90}Sr and the external gamma dose is a maximum. Figure 3 is a graphical illustration of this point. The maximum annual doses

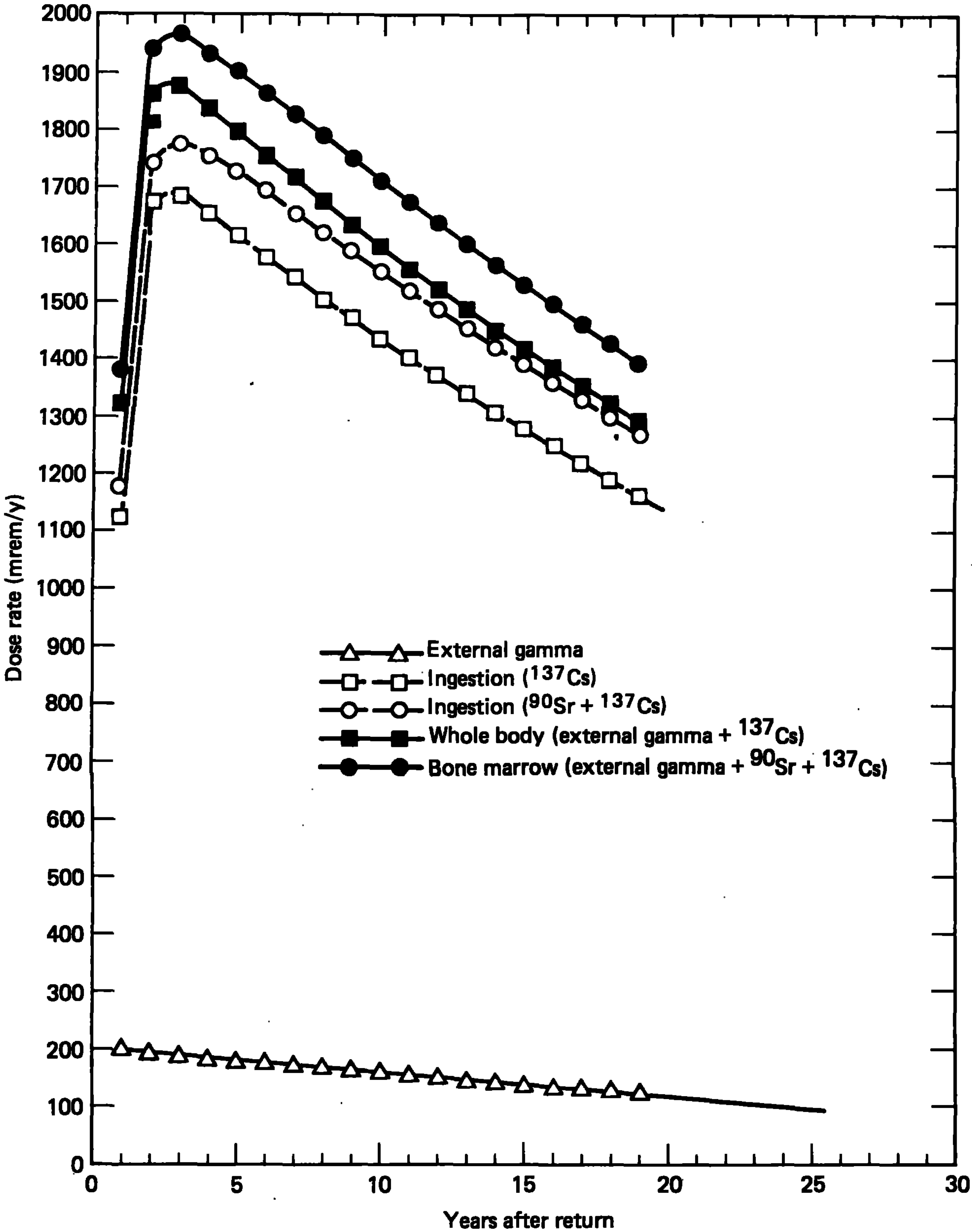


Figure 3. Maximum annual dose rates for whole body and bone marrow and the corresponding external gamma dose.

for different living patterns are listed in Tables 23 through 26 for bone marrow and whole body for both imports-available and imports-unavailable conditions; they are broken down into ingestion and external gamma contributions. The year where the maximum dose rate occurs is also listed. It is emphasized that doses listed for the imports-unavailable conditions are calculated assuming continuous consumption of local foods over a lifetime with limited use of imports. This is not a reasonable dietary pattern but it is presented to show the maximum case that could occur. Imported foods are not expected to be unavailable for more than a month or two each year based on current lifestyle and projected expectations of the Bikini people.

Table 23 shows the maximum annual dose rate for Bikini Island. When imported foods are available, the maximum annual dose rates for whole body and bone marrow are slightly greater than 1000 mrem (1 rem). For the case where imported foods are unavailable, both whole-body and bone-marrow dose rates are about 2000 mrem (2 rem). The maximum annual dose rates for Eneu Island (Table 24) are much less than for Bikini Island: 130 and 140 mrem/y for whole body and bone marrow, respectively, when imported foods are available. When imported foods are unavailable, the whole-body dose rate is 250 mrem/y and the bone-marrow dose rate is 260 mrem/y. For the intermediate living patterns where Eneu Island is the residence island but some time is spent on Bikini Island and some of the diet is likewise from Bikini, the dose rates fall between those listed above for the individual island living patterns. For example, when 50% of the time is spent on Bikini Island and 50% of the diet comes from Bikini, the maximum annual whole-body and bone-marrow doses are 570 and 590 mrem/y, respectively, when imported foods are available (Table 25). The estimated dose rates are about 1060 and 1110 mrem/y for whole body and bone marrow, respectively, when imported foods are unavailable. Table 26 shows the dose rates when Eneu Island is the residence island and all locally grown foods come from Eneu but 10% of the time is spent on Bikini Island. When imports are available, the maximum annual whole-body and bone-marrow dose is about 150 mrem/y. The dose rates are 260 and 280 mrem/y for whole body and bone marrow, respectively, when imported foods are unavailable.

The dose commitments, or 30-y integral doses, for each of the living patterns are listed in Tables 27 through 30. The 30-y doses when imported foods are available range from 22 rem for whole body and 23 rem for bone marrow at Bikini Island to 2.9 rem for whole body and 3.1 rem for bone marrow at Eneu Island. When imported foods are unavailable, the whole body and bone marrow doses for Bikini Island are 42 and 45 rem, respectively, and for Eneu Island they are 5.5 and 6.1 rem, respectively. The two variations for the Eneu Island living pattern fall between these extremes. The 50-y integral doses for the different living patterns are given in Tables 31 through 34.

Table 23. Maximum annual dose rates in millirems per year for adults for a living pattern consisting of 100% time on Bikini Island and all locally grown foods from Bikini Island.

Organ	Radionuclide ingestion[a]	External gamma[b]	Total	Year of maximum dose
		Imports available		
Whole body	815	189	1000	3
Bone marrow	845	189	1030	3
		Imports unavailable		
Whole body	1685	189	1870	3
Bone marrow	1775	189	1960	3

[a] Whole-body ingestion dose from ^{137}Cs. Bone-marrow ingestion dose from ^{137}Cs and ^{90}Sr.

[b] Background subtracted.

Table 24. Maximum annual dose rates in millirems per year for adults for a living pattern consisting of 100% time on Eneu Island and all locally grown foods from Eneu Island.

Organ	Radionuclide ingestion[a]	External gamma[b]	Total	Year of maximum dose
		Imports available		
Whole body	116	14	130	3
Bone marrow	122	14	140	3
		Imports unavailable		
Whole body	231	14	250	3
Bone marrow	249	14	260	3

[a] Whole-body ingestion dose from ^{137}Cs. Bone-marrow ingestion dose from ^{137}Cs and ^{90}Sr.

[b] Background subtracted.

Table 25. Maximum annual dose rates in millirems per year for adults for a living pattern consisting of 50% of the diet and time associated with Eneu Island and the other 50% associated with Bikini Island.

Organ	Radionuclide ingestion[a]	External gamma[b]	Total	Year of maximum dose
		Imports available		
Whole body	465	102	570	3
Bone marrow	483	102	590	3
		Imports unavailable		
Whole body	958	102	1060	3
Bone marrow	1012	102	1110	3

[a] Whole-body ingestion dose from ^{137}Cs. Bone-marrow ingestion dose from ^{137}Cs and ^{90}Sr.

[b] Background subtracted.

Table 26. Maximum annual dose rates in millirems per year for adults for a living pattern consisting of 90% time on Eneu Island and 10% time on Bikini Island and all locally grown foods from Eneu Island.

Organ	Radionuclide ingestion[a]	External gamma[b]	Total	Year of maximum dose
		Imports available		
Whole body	116	32	150	3
Bone marrow	122	32	150	3
		Imports unavailable		
Whole body	231	32	260	3
Bone marrow	249	32	280	3

[a] Whole-body ingestion dose from ^{137}Cs. Bone-marrow ingestion dose from ^{137}Cs and ^{90}Sr.

[b] Background subtracted.

Table 27. The 30-y integral doses in rem for adults for a living pattern consisting of 100% time on Bikini Island and all locally grown foods from Bikini Island.

Pathway and radionuclide	Imports available		Imports unavailable	
	Whole body	Bone marrow	Whole body	Bone marrow
Ingestion				
^{137}Cs	18	18	38	38
^{90}Sr	--	1	--	3
$^{239+240}Pu$[a]		0.00048	--	0.0016
^{241}Am[a]	--	0.0013	--	0.0041
External gamma[b]				
$^{137}Cs + ^{60}Co$	4.2	4.2	4.2	4.2
Inhalation[a]				
$^{239+240}Pu$	--	0.13	--	0.13
^{241}Am	--	0.14	--	0.14
^{241}Pu (^{241}Am)	--	0.02	--	0.02
TOTAL	22	23	42	45

[a] Doses to mineral bone not bone marrow; bone-marrow doses approximately one fourth of these values.

[b] Background subtracted.

Table 28. The 30-y integral doses in rem for adults for a living pattern consisting of 100% time on Eneu Island and all locally grown foods from Eneu Island.

Pathway and radionuclide	Imports available		Imports unavailable	
	Whole body	Bone marrow	Whole body	Bone marrow
Ingestion				
^{137}Cs	2.6	2.6	5.2	5.2
^{90}Sr	--	0.2	--	0.61
$^{239+240}Pu$[a]	--	0.00044	--	0.0015
^{241}Am[a]	--	0.0014	--	0.0044
External gamma[b]				
$^{137}Cs + ^{60}Co$	0.32	0.32	0.32	0.32
Inhalation[a]				
$^{239+240}Pu$	--	0.0096	--	0.0096
^{241}Am	--	0.0065	--	0.0065
^{241}Pu (^{241}Am)	--	0.0015	--	0.0015
TOTAL	2.9	3.1	5.5	6.1

[a]Doses to mineral bone not bone marrow; bone-marrow doses approximately one fourth of these values.

[b] Background subtracted.

Table 29. The 30-y integral doses in rem for adults for a living pattern consisting of 50% of the diet and time associated with Eneu Island and the other 50% associated with Bikini Island.

Pathway and radionuclide	Imports available		Imports unavailable	
	Whole body	Bone marrow	Whole body	Bone marrow
Ingestion				
^{137}Cs	11	11	22	22
^{90}Sr	--	0.6	--	1.8
$^{239+240}Pu$[a]	--	0.00046	--	0.0015
^{241}Am[a]	--	0.0013	--	0.0043
External gamma[b]				
$^{137}Cs + {}^{60}Co$	2.3	2.3	2.3	2.3
Inhalation[a]				
$^{239+240}Pu$	--	0.072	--	0.072
^{241}Am	--	0.067	--	0.067
^{241}Pu (^{241}Am)	--	0.011	--	0.011
TOTAL	13	14	25	27

[a] Doses to mineral bone not bone marrow; bone-marrow doses approximately one fourth of these values.

[b] Background subtracted.

Table 30. The 30-y integral doses in rem for adults for a living pattern consisting of 90% time on Eneu Island and 10% on Bikini Island and all locally grown foods from Eneu Island.

Pathway and radionuclide	Imports available		Imports unavailable	
	Whole body	Bone marrow	Whole body	Bone marrow
Ingestion				
^{137}Cs	2.6	2.6	5.2	5.2
^{90}Sr	--	0.2	--	0.61
$^{239+240}Pu$[a]	--	0.00044	--	0.0015
^{241}Am[a]	--	0.0014	--	0.0044
External gamma[b]				
$^{137}Cs + {}^{60}Co$	0.71	0.71	0.71	0.71
Inhalation[a]				
$^{239+240}Pu$	--	0.021	--	0.021
^{241}Am	--	0.02	--	0.02
^{241}Pu (^{241}Am)	--	0.0034	--	0.0034
TOTAL	3.3	3.5	6.1	6.5

[a] Doses to mineral bone not bone marrow; bone-marrow doses approximately one fourth of these values.

[b] Background subtracted.

Table 31. The 50-y integral doses in rem for adults for a living pattern consisting of 100% time on Bikini Island and all locally grown foods from Bikini Island.

Pathway and radionuclide	Imports available		Imports unavailable	
	Whole body	Bone marrow	Whole body	Bone marrow
Ingestion				
^{137}Cs	25	25	52	52
^{90}Sr	--	1.4	--	4.3
$^{239+240}Pu^{a}$	--	0.0013	--	0.0041
$^{241}Am^{a}$	--	0.0034	--	0.011
External gamma[b]				
$^{137}Cs + ^{60}Co$	5.8	5.8	5.8	5.8
Inhalation[a]				
$^{239+240}Pu$	--	0.37	--	0.37
^{241}Am	--	0.37	--	0.37
^{241}Pu (^{241}Am)	--	0.073	--	0.073
TOTAL	31	32	58	63

[a] Doses to mineral bone not bone marrow; bone-marrow doses approximately one fourth of these values.

[b] Background subtracted.

Table 32. The 50-y integral doses in rem for adults for a living pattern consisting of 100% time on Eneu Island and all locally grown foods from Eneu Island.

Pathway and radionuclide	Imports available		Imports unavailable	
	Whole body	Bone marrow	Whole body	Bone marrow
Ingestion				
^{137}Cs	3.6	3.6	7.2	7.2
^{90}Sr	--	0.28	--	0.86
$^{239+240}Pu$[a]	--	0.0012	--	0.0041
^{241}Am[a]	--	0.0036	--	0.012
External gamma[b]				
$^{137}Cs + ^{60}Co$	0.44	0.44	0.44	0.44
Inhalation[a]				
$^{239+240}Pu$	--	0.029	--	0.029
^{241}Am	--	0.017	--	0.017
^{241}Pu (^{241}Am)	--	0.0057	--	0.0057
TOTAL	4	4.3	7.6	8.5

[a] Doses to mineral bone not bone marrow; bone-marrow doses approximately one fourth of these values.

[b] Background subtracted.

Table 33. The 50-y integral doses in rem for adults for a living pattern consisting of 50% of the diet and time associated with Eneu Island and the other 50% associated with Bikini Island.

Pathway and radionuclide	Imports available		Imports unavailable	
	Whole body	Bone marrow	Whole body	Bone marrow
Ingestion				
^{137}Cs	15	15	30	30
^{90}Sr	--	0.85	--	2.6
$^{239+240}Pu$[a]	--	0.0012	--	0.0041
^{241}Am[a]	--	0.0035	--	0.011
External gamma[b]				
$^{137}Cs + ^{60}Co$	3.1	3.1	3.1	3.1
Inhalation[a]				
$^{239+240}Pu$	--	0.2	--	0.2
^{241}Am	--	0.19	--	0.19
^{241}Pu (^{241}Am)	--	0.04	--	0.04
TOTAL	18	19	33	36

[a] Doses to mineral bone not bone marrow; bone-marrow doses approximately one fourth of these values.

[b] Background subtracted.

Table 34. The 50-y integral doses in rem for adults for a living pattern consisting of 90% time on Eneu Island and 10% on Bikini Island and all locally grown foods from Eneu Island.

Pathway and radionuclide	Imports available		Imports unavailable	
	Whole body	Bone marrow	Whole body	Bone marrow
Ingestion				
^{137}Cs	3.6	3.6	7.2	7.2
^{90}Sr	--	0.28	--	0.86
$^{239+240}Pu$[a]	--	0.0012	--	0.0041
^{241}Am[a]	--	0.0036	--	0.012
External gamma[b]				
$^{137}Cs + ^{60}Co$	0.97	0.97	0.97	0.97
Inhalation[a]				
$^{239+240}Pu$	--	0.063	--	0.063
^{241}Am	--	0.053	--	0.053
^{241}Pu (^{241}Am)	--	0.0012	--	0.0012
TOTAL	4.6	4.9	8.2	9

[a] Doses to mineral bone not bone marrow; bone-marrow doses approximately one fourth of these values.

[b] Background subtracted.

The ingestion pathway shown in Tables 27 through 34 includes radionuclide intake via the terrestrial food chain, the marine food chain, and drinking water. The major share of the estimated dose from ingestion results from intake via the terrestrial food chain. The dose rates for the drinking water and marine food chain pathways are listed in Tables 35 through 38. To show the small contribution they make to the doses listed in Tables 27 through 34, a comparison of the 30-y integral dose for the various pathways is shown in Table 39.

We have also estimated the maximum annual dose rates and 30-y integral doses for Eneu Island based on maximum quantities of food prepared for a household as reported in the BNL study (Ref. 6). The results are listed in Tables 40 and 41 with the assumption that imported foods are available. The estimated dose rate for whole body is 365 mrem/y and for bone marrow it is 378 mrem/y. The doses are presented only to show the upper range based on the highest values we have seen in any published literature on current

Table 35. Maximum annual dose rates in millirems per year for adults for Bikini and Eneu Islands assuming a 2 liter/d intake of either cistern water or groundwater.

	Cistern water		Groundwater	
Island	Whole body	Bone marrow	Whole body	Bone marrow
Bikini	0.075	0.22	17	43
Eneu	0.012	0.073	1.2	8.6

Table 36. The 30-y integral doses in rem for adults for Bikini and Eneu Islands assuming a 2 liter/d intake of either cistern water or groundwater.

	Cistern water		Groundwater	
Island	Whole body	Bone marrow	Whole body	Bone marrow
Bikini	0.0017	0.0056	0.19	0.55
Eneu	0.00028	0.0019	0.014	0.11

Table 37. Maximum annual dose rates in millirems per year for adults for the marine food chain at Bikini Atoll.

	Imports available		Imports unavailable	
Atoll	Whole body	Bone marrow	Whole body	Bone marrow
Bikini	0.16	0.27	0.48	1

Table 38. The 30-y integral doses in rem for adults for the marine food chain at Bikini Atoll.

Atoll	Imports available		Imports unavailable	
	Whole body	Bone marrow	Whole body	Bone marrow
Bikini	0.0037	0.0072	0.011	0.027

Table 39. Comparison of the 30-y integral dose contributions in rem for adults for five exposure pathways at Bikini and Eneu Islands when imported foods are available.

Pathway	Bikini Island			Eneu Island		
	Whole body	Bone marrow	Lung	Whole body	Bone marrow	Lung
Terrestrial foods	18	20	19	2.6	2.8	2.6
External gamma	4.2	4.2	4.2	0.32	0.32	0.32
Marine foods	0.0037	0.0072	0.0037	0.0037	0.0072	0.0037
Inhalation	--	0.29[a]	--	--	0.018[a]	--
Cistern water	0.0017	0.0056	0.0017	0.00028	0.0019	0.00028
Groundwater	0.19	0.55	0.19	0.014	0.11	0.014

[a] Dose to mineral bone not bone marrow; bone-marrow dose approximately one fourth of this value.

Table 40. Eneu Island maximum annual dose rates in millirems per year for adults using the BNL survey data on the amount of coconut meat, coconut fluid, Pandanus, and fish prepared for a household when imported foods are available.

	Radionuclide ingestion[a]	External gamma	Total	Year of maximum dose
Whole body	351	14	365	3
Bone marrow	364	14	378	3

[a] Whole-body ingestion dose from ^{137}Cs. Bone-marrow ingestion dose from ^{137}Cs and ^{90}Sr.

Table 41. Eneu Island 30-y integral doses in rem for adults using the BNL survey data on the amount of coconut meat, coconut fluid, Pandanus, and fish, prepared for a household when imported foods are available.

Pathway and radionuclide	Whole body	Bone marrow
Ingestion		
^{137}Cs	7.9	7.9
^{90}Sr	--	0.45
$^{239+240}Pu$[a]	--	0.00097
^{241}Am	--	0.031
External gamma[b]		
$^{137}Cs + ^{60}Co$	0.32	0.32
Inhalation[a]		
$^{239+240}Pu$	--	0.0042
^{241}Am	--	0.0034
^{241}Pu (^{241}Am)	--	0.00068
TOTAL	8.2	8.7

[a] Doses to mineral bone not bone marrow; bone-marrow doses approximately one fourth of these values.

[b] Background subtracted.

Marshallese diets for coconut meat, coconut fluid, Pandanus fruit, and fish. The quantities listed in the BNL study are food prepared and not necessarily food consumed. In fact, the authors feel the values listed are definitely overestimates as far as food consumption is concerned because some of the prepared food is shared with other families and fed to the animals. Therefore the doses are not considered the most reasonable estimate of the average dose for Eneu Island.

The doses calculated for a child born at the time of return are listed in Tables 42 through 45. The maximum annual whole-body dose rate at Bikini Island when imported foods are available is 750 mrem/y compared with 1000 mrem/y for the adults; for Eneu Island it is 93 mrem/y compared with the adult dose of 130 mrem/y. Similar differences exist when imported foods are unavailable and for bone-marrow annual doses.

Table 42. Maximum annual dose rates in millirems per year for children for a living pattern consisting of 100% time on Bikini Island and all locally grown foods from Bikini Island.

Organ	Radionuclide ingestion[a]	External gamma[b]	Total	Year of maximum dose
		Imports available		
Whole body	564	189	750	19
Bone marrow	602	189	790	19
		Imports unavailable		
Whole body	1156	189	1350	19
Bone marrow	1274	189	1460	19

[a] Whole-body ingestion dose from ^{137}Cs. Bone-marrow ingestion dose from ^{137}Cs and ^{90}Sr.

[b] Background subtracted.

Table 43. Maximum annual dose rates in millirems per year for children for a living pattern consisting of 100% time on Eneu Island and all locally grown foods from Eneu Island.

Organ	Radionuclide ingestion[a]	External gamma[b]	Total	Year of maximum dose
		Imports available		
Whole body	79.4	14	93	19
Bone marrow	87.6	14	100	19
		Imports unavailable		
Whole body	159	14	170	19
Bone marrow	193	14	210	19

[a] Whole-body ingestion dose from ^{137}Cs. Bone-marrow ingestion dose from ^{137}Cs and ^{90}Sr.

[b] Background subtracted.

Table 44. The 30-y integral doses in rem for child through adult for a living pattern consisting of 100% time on Bikini Island and all locally grown foods from Bikini Island.

Pathway and radionuclide	Imports available		Imports unavailable	
	Whole body	Bone marrow	Whole body	Bone marrow
Ingestion				
^{137}Cs	15	15	30	30
^{90}Sr	--	0.89	--	2.79
$^{239+240}Pu$[a]	--	0.00043	--	0.0014
^{241}Am[a]	--	0.0011	--	0.0037
External gamma[b]				
$^{137}Cs + {}^{60}Co$	4.2	4.2	4.2	4.2
Inhalation[a,c]				
$^{239+240}Pu$	--	0.37	--	0.37
^{241}Am	--	0.37	--	0.37
^{241}Pu (^{241}Am)	--	0.073	--	0.073
TOTAL	19	20	34	37

[a] Doses to mineral bone not bone marrow; bone-marrow doses approximately one fourth of these values.

[b] Background subtracted.

[c] Assumed to be the same as the adult.

Table 45. The 30-y integral doses in rem for child through adult for a living pattern consisting of 100% time on Eneu Island and all locally grown foods from Eneu Island.

Pathway and radionuclide	Imports available		Imports unavailable	
	Whole body	Bone marrow	Whole body	Bone marrow
Ingestion				
^{137}Cs	2.1	2.1	4.2	4.2
^{90}Sr	--	0.2	--	0.75
$^{239+240}Pu$[a]	--	0.0004	--	0.0015
^{241}Am[a]	--	0.0012	--	0.004
External gamma[b]				
$^{137}Cs + {}^{60}Co$	0.32	0.32	0.32	0.32
Inhalation[a,c]				
$^{239+240}Pu$	--	0.029	--	0.029
^{241}Am	--	0.017	--	0.017
^{241}Pu (^{241}Am)	--	0.0057	--	0.0057
TOTAL	2.4	2.6	4.5	5.3

[a] Doses to mineral bone not bone marrow; bone-marrow doses approximately one fourth of these values.

[b] Background subtracted.

[c] Assumed to be the same as the adult.

Comparison of 30-y integral doses when imported foods are available show a whole-body dose for children of 19 rem for Bikini Island and 2.4 rem for Eneu Island compared with adult doses of 22 and 2.9 rem, respectively. Similar differences exist when imported foods are unavailable and for bone-marrow doses.

DISTRIBUTION OF DOSES AROUND THE ESTIMATED AVERAGE DOSE

The doses presented herein are calculated using the mean value of the data available for each parameter in the dose models. For example, model parameters include body weight, residence time of radionuclides in the body, radionuclide concentrations in either foods or soil, dietary intake (measured in grams per day), and fractional deposition of radionuclides in body organs or compartments. Data for all of these parameters have a log-normal distribution. Thus the mean value calculated from the data does not represent the midpoint of the distribution but rather falls somewhere above the 50th percentile point in the distribution.

Figures 4 and 5 show the distributions for body weight, Figs. 6 and 7 for dietary intake, Fig. 8 for ^{137}Cs whole-body residence time, Figs. 9 and 10 for ^{137}Cs soil concentration, and Figs. 11 through 16 for ^{137}Cs concentration in coconut meat and fluid. The mean values fall between the 65 to 70th percentile; that is, for a given parameter approximately 65 to 70% of the data points fall below the mean value. Thus, if the mean values for the parameters are used in the dose models and the data sets are log-normally distributed, where do the final calculated average doses fall on the distribution of final doses? This complex problem requires a computer analysis of the type of distribution and the associated variance for each parameter in the model to determine the distribution of estimated doses and the associated variance.

In our case, for the estimated doses at Bikini Atoll, ^{137}Cs accounts for approximately 85% of the total dose. Therefore, focusing only on ^{137}Cs we have used a Monte Carlo method to determine the distribution in the final dose estimates. The impact on the final distribution of ignoring the ^{90}Sr component will be small. Adding the ^{90}Sr component greatly adds to the complexity of the analyses, but we are in the process of incorporating it in this type of analysis. However, as mentioned, because the ^{137}Cs accounts for such a large portion of the dose, the analysis of ^{137}Cs will essentially reveal the variation in the final doses and the dose contribution from ^{90}Sr will have a small effect on the final dose distribution.

The method for calculating the distribution in the final dose is based on the distribution of each of the model parameters and is briefly reviewed here. The 30-y cumulative dose for the ingestion of ^{137}Cs has been simulated using Monte Carlo techniques.

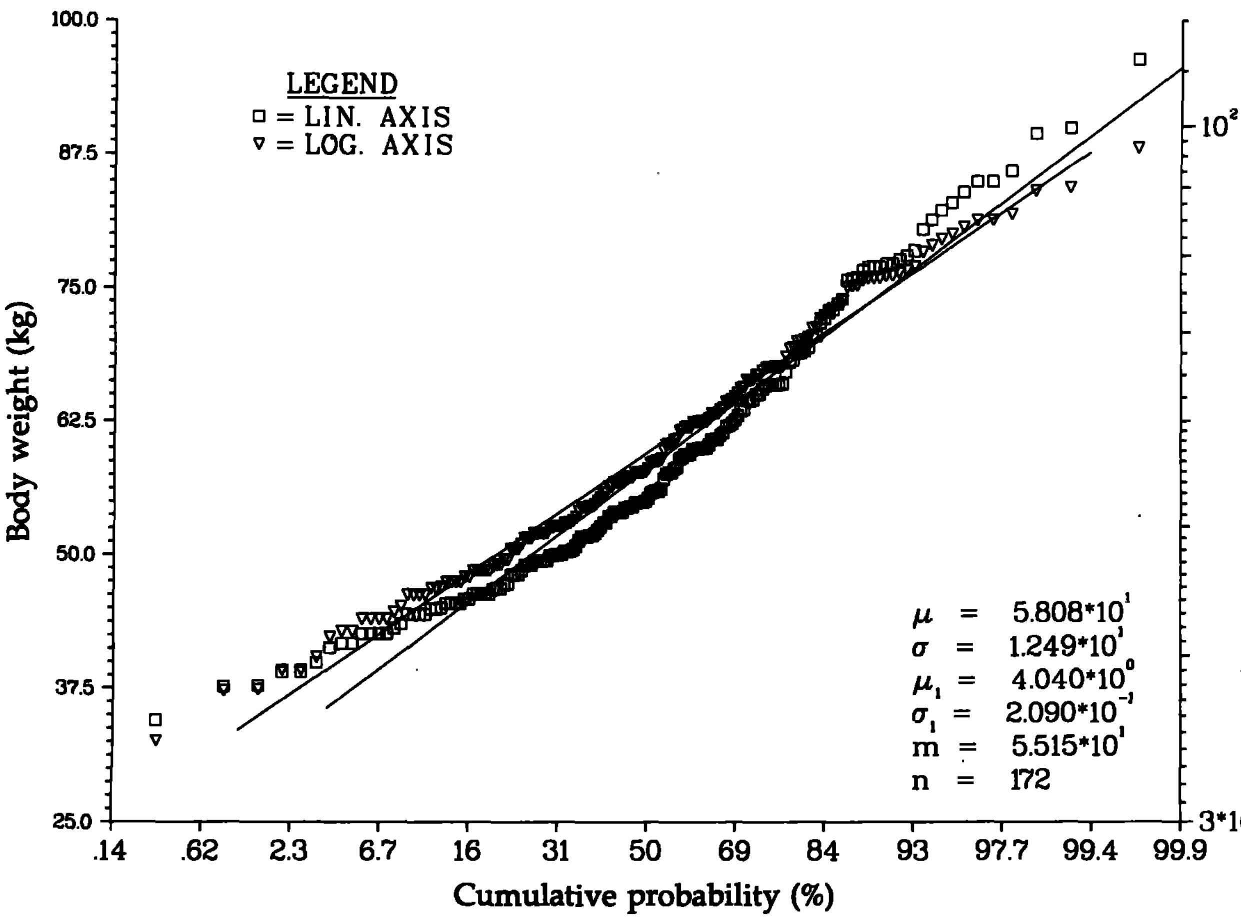


Figure 4. Log probability plot for the body weight of 172 adult Marshallese females.

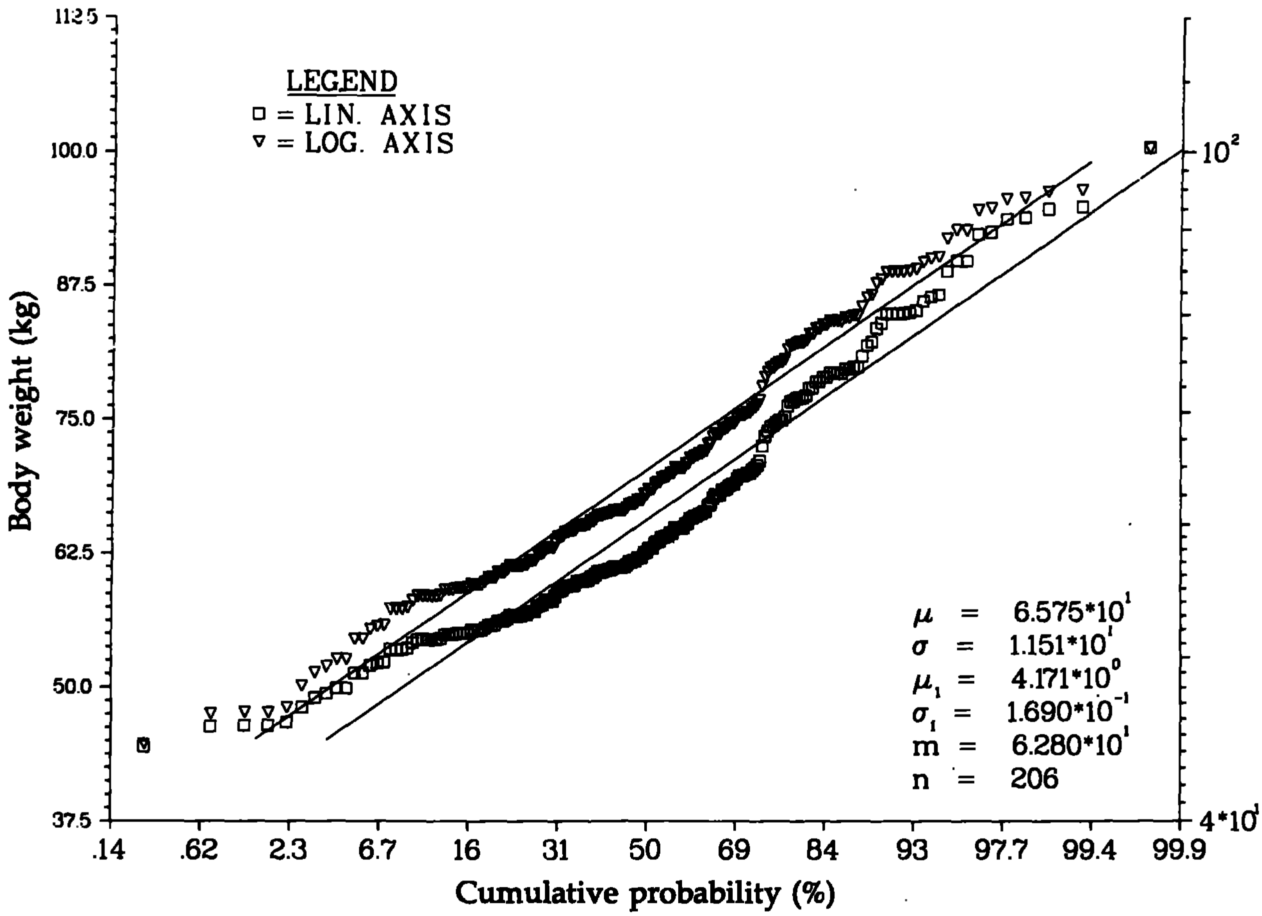


Figure 5. Log probability plot for the body weight of 206 adult Marshallese males.

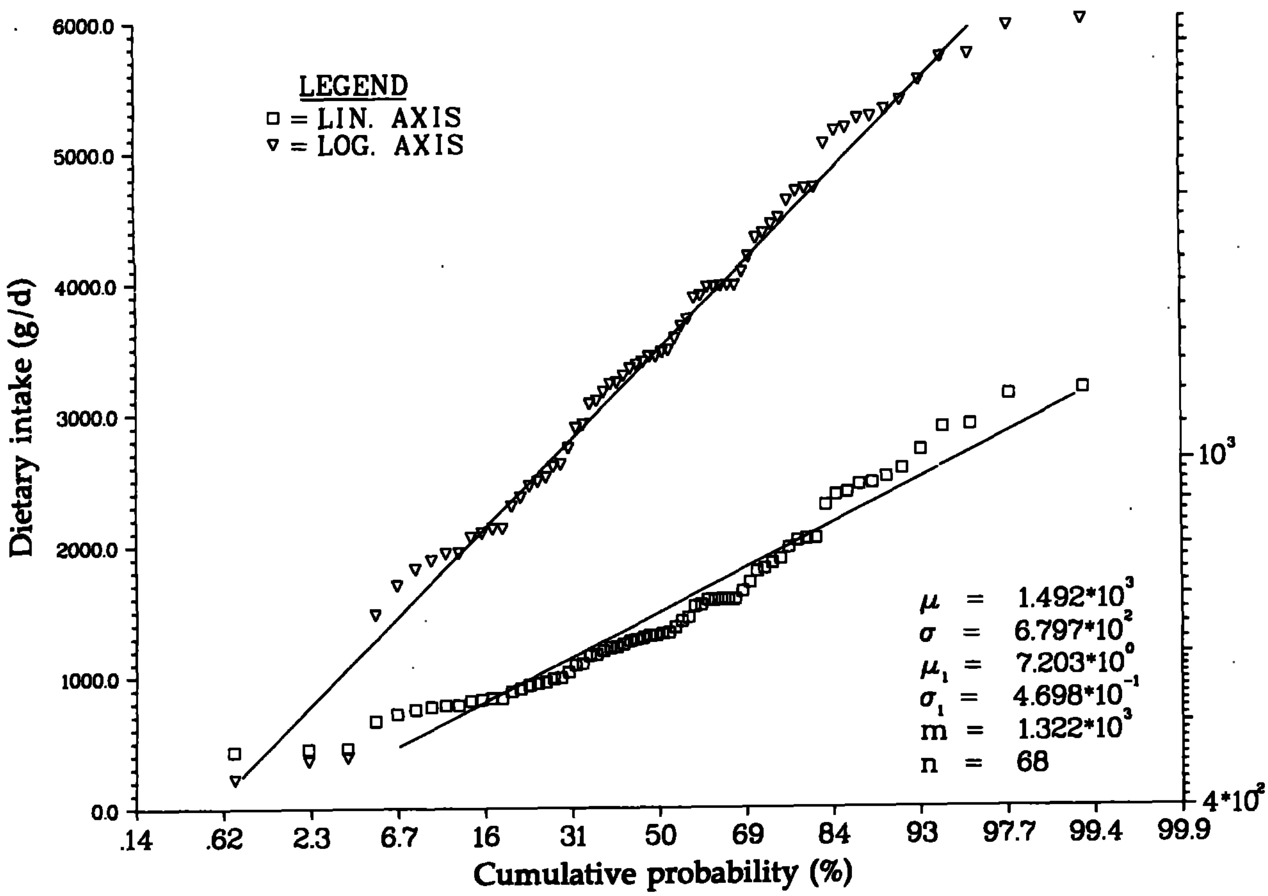


Figure 6. Log probability plot of the dietary intake of 34 Marshallese females.

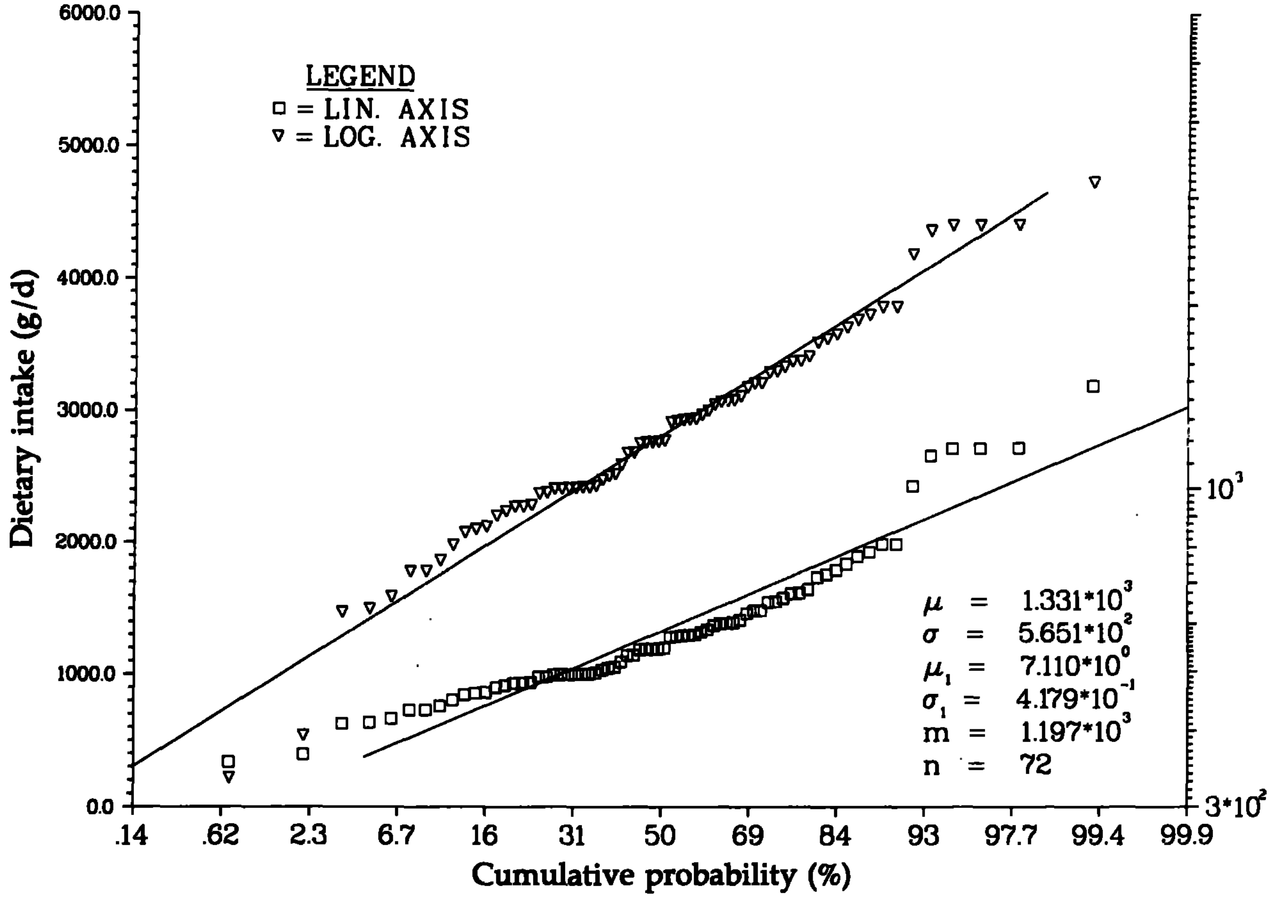
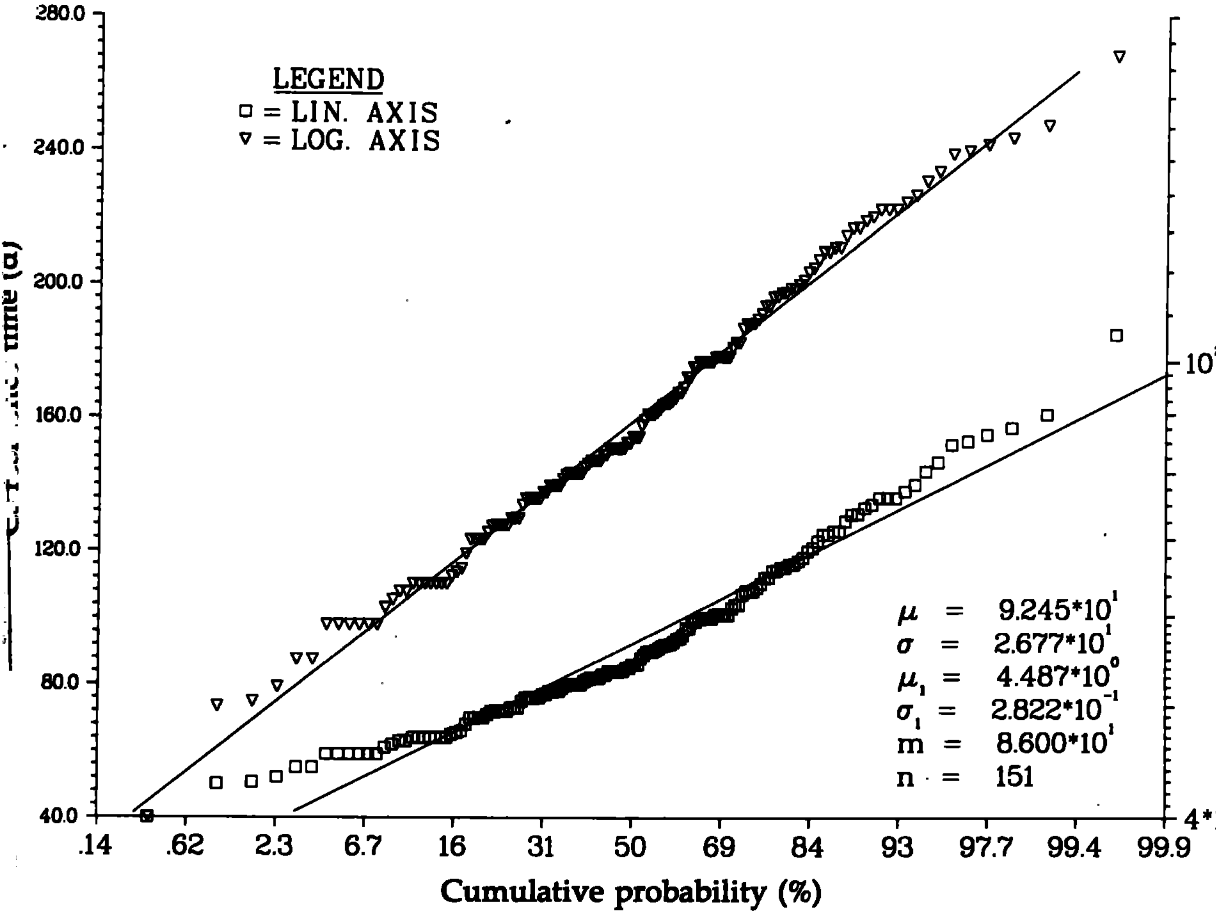


Figure 7. Log probability plot of the dietary intake of 36 Marshallese males.



ure 8. Log probability plot of the residence time of ^{137}Cs in the body of 152 adult arshallese males.

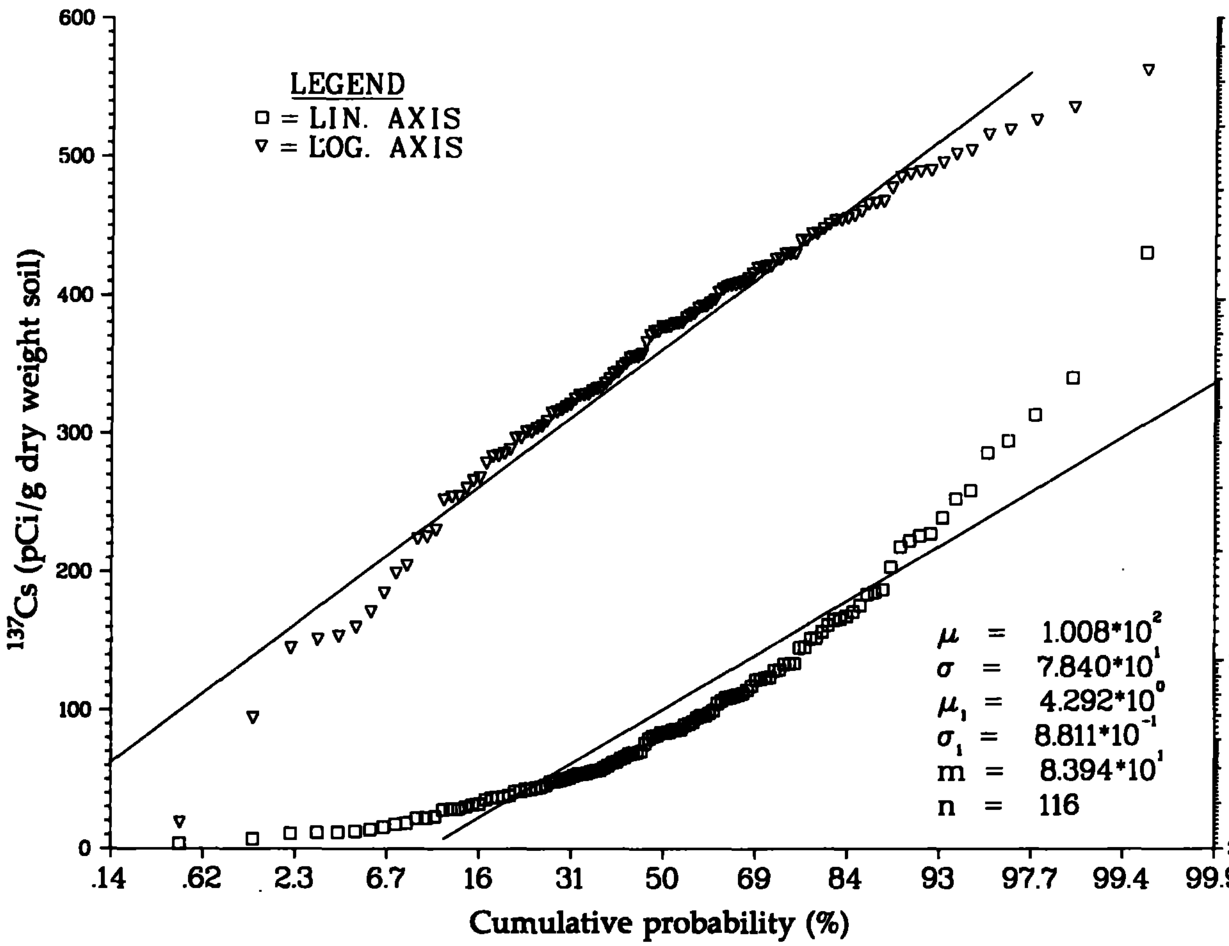
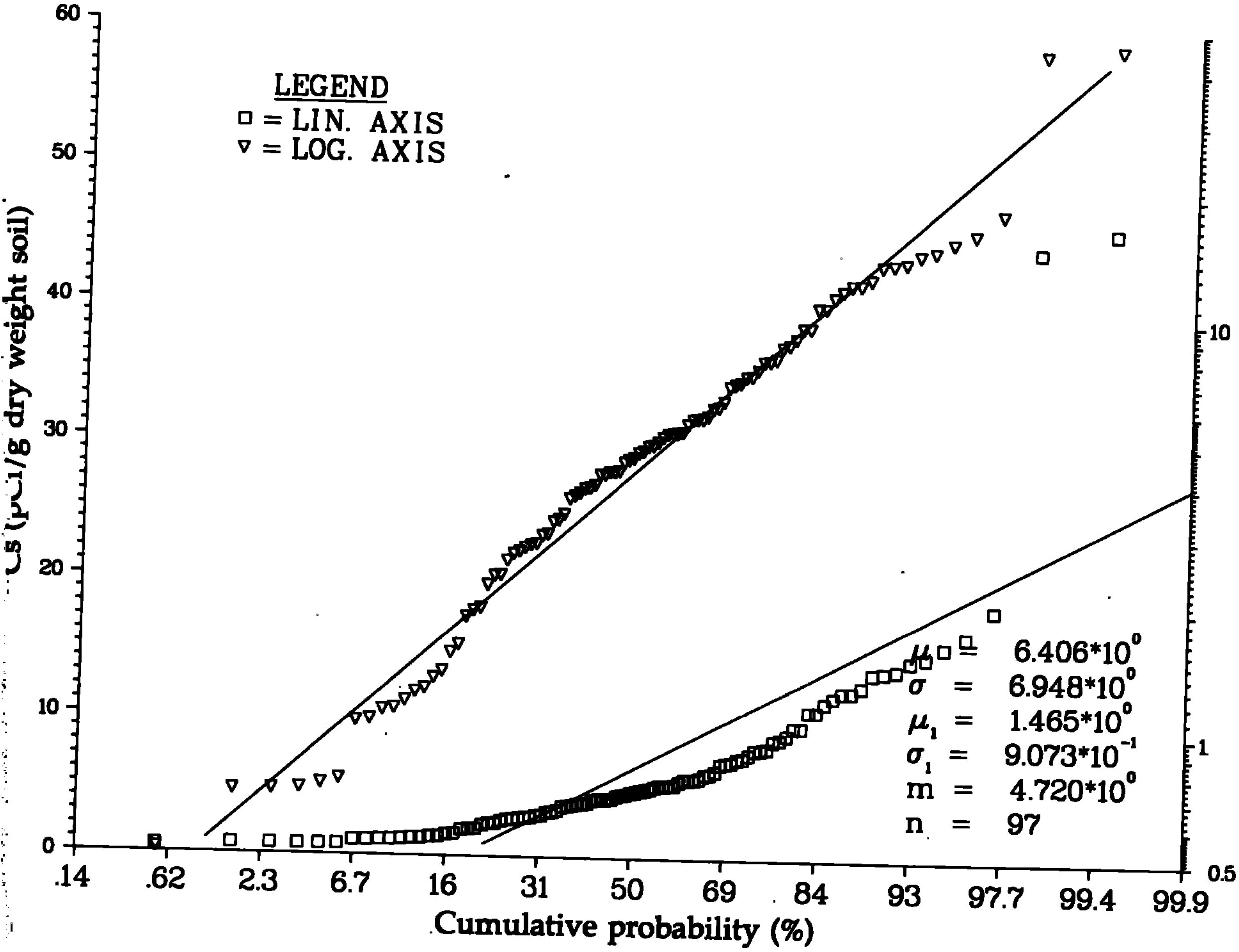


Figure 9. Log probability plot of ^{137}Cs concentration in the top 0 to 5 cm of soil at Bikini Island.



igure 10. Log probability plot of ^{137}Cs concentration in the top 0 to 5 cm of soil at neu Island.

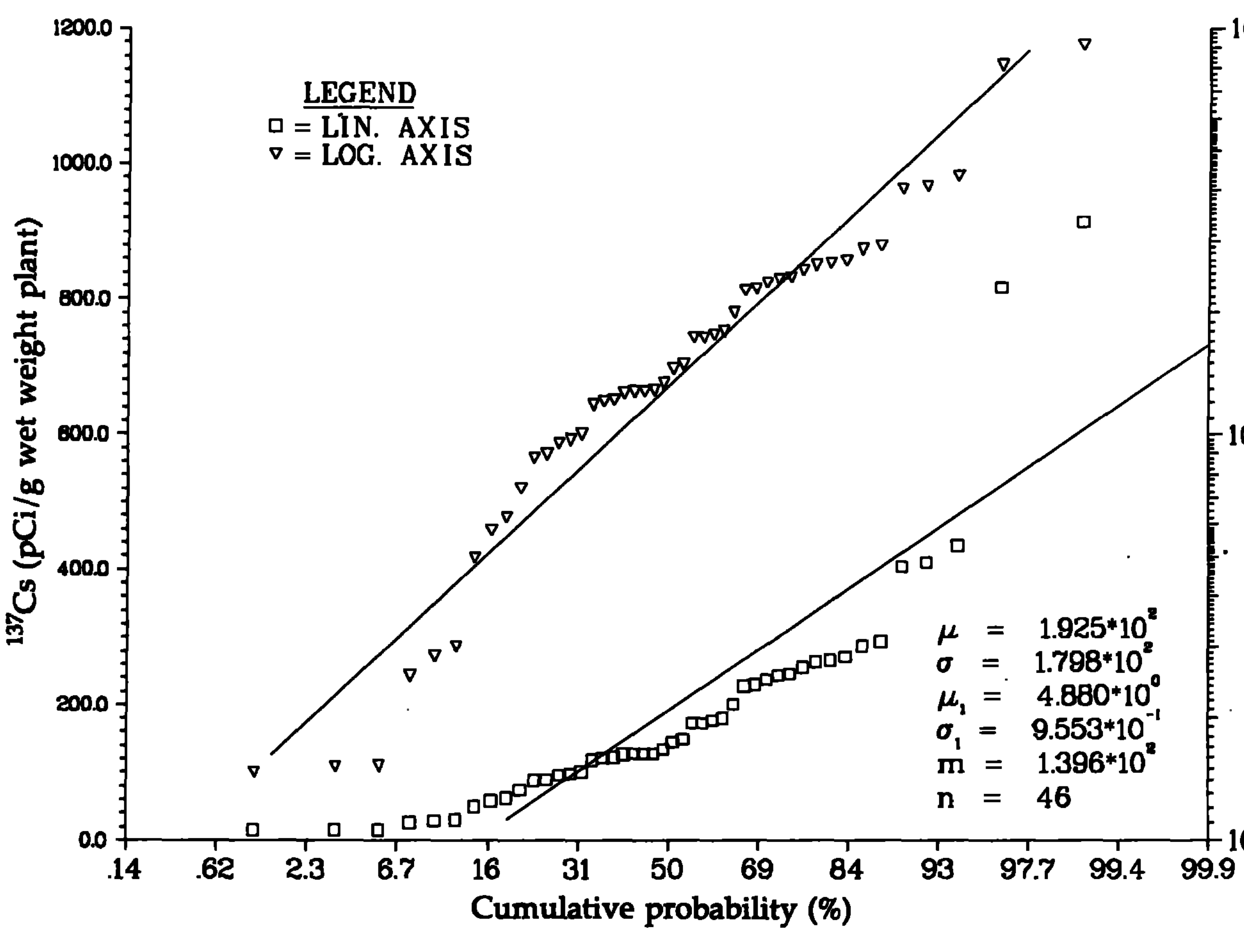


Figure 11. Log probability plot of ^{137}Cs concentration in drinking coconut meat on Bikini Island.

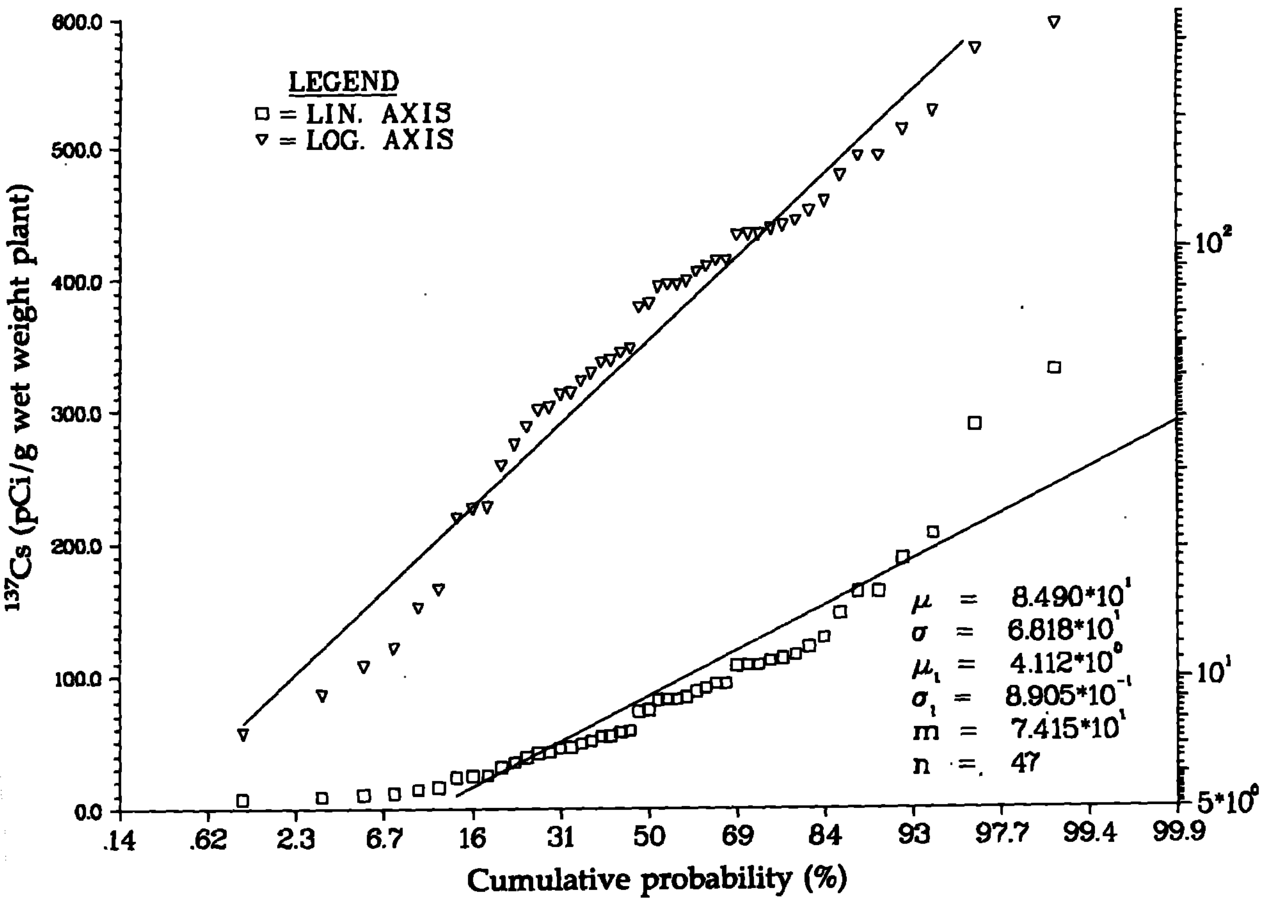


Figure 12. Log probability plot of ^{137}Cs concentration in drinking coconut fluid on Bikini Island.

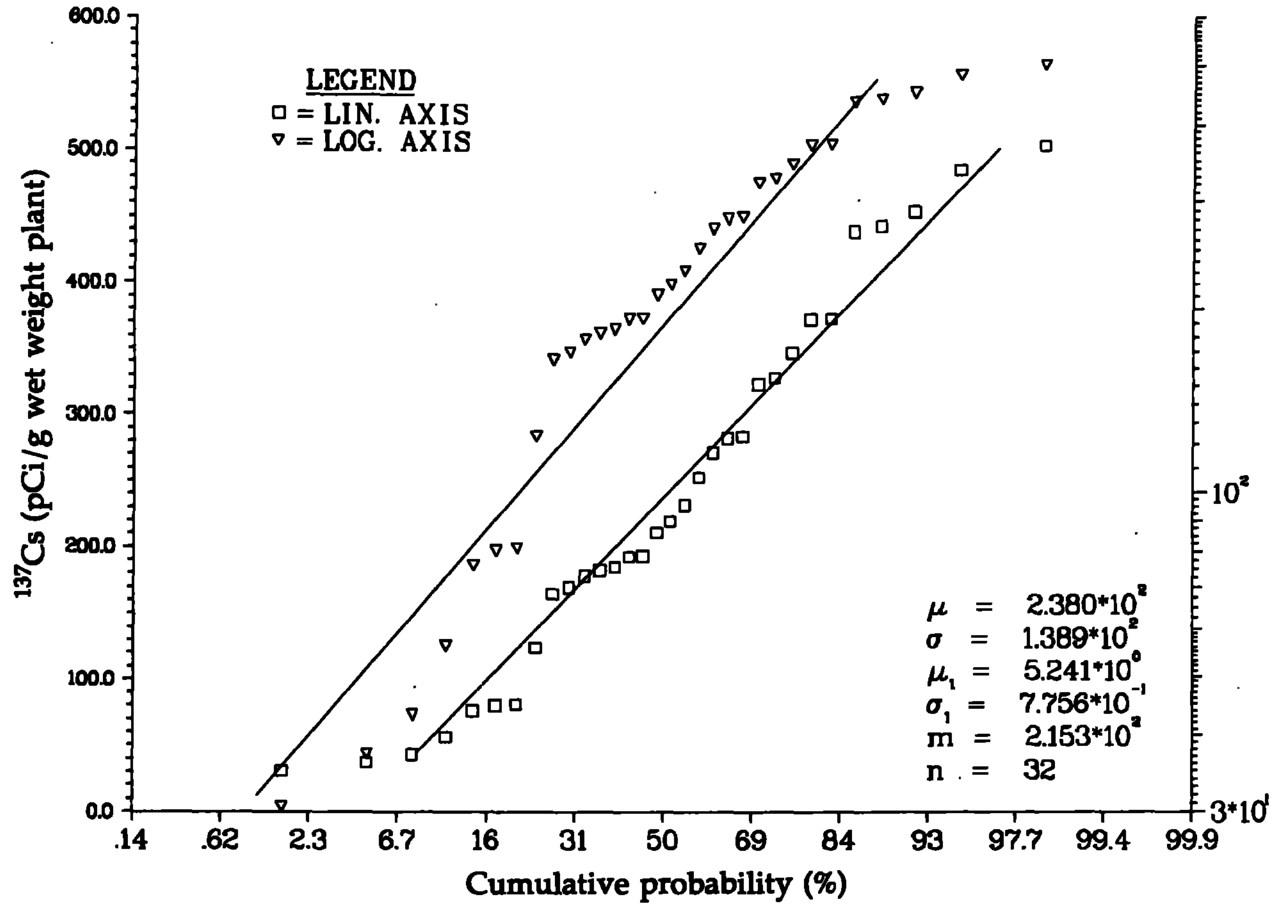


Figure 13. Log probability plot of ^{137}Cs concentration in copra meat on Bikini Island.

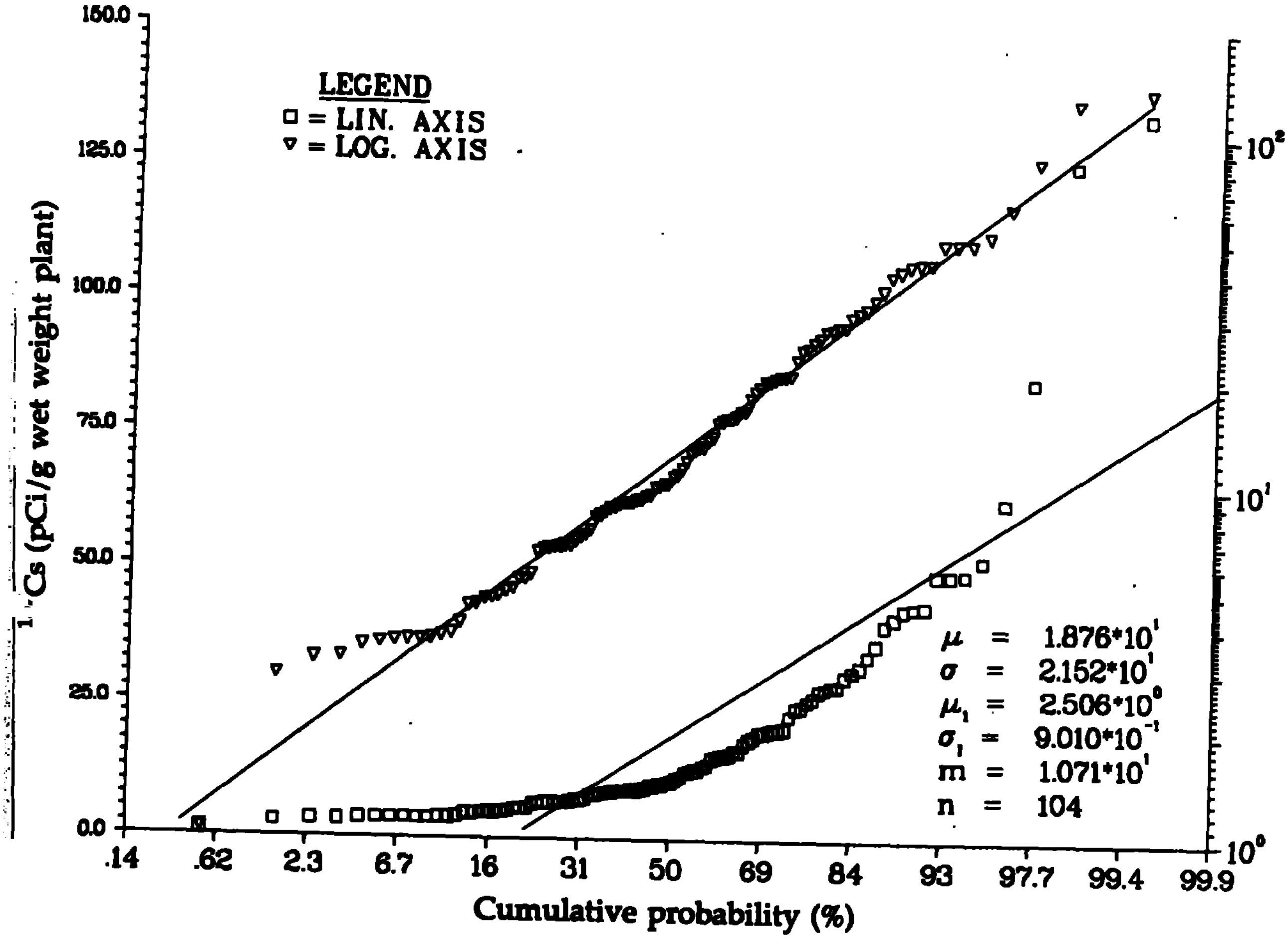


Figure 14. Log probability plot of ^{137}Cs concentration in drinking coconut meat on Eneu Island.

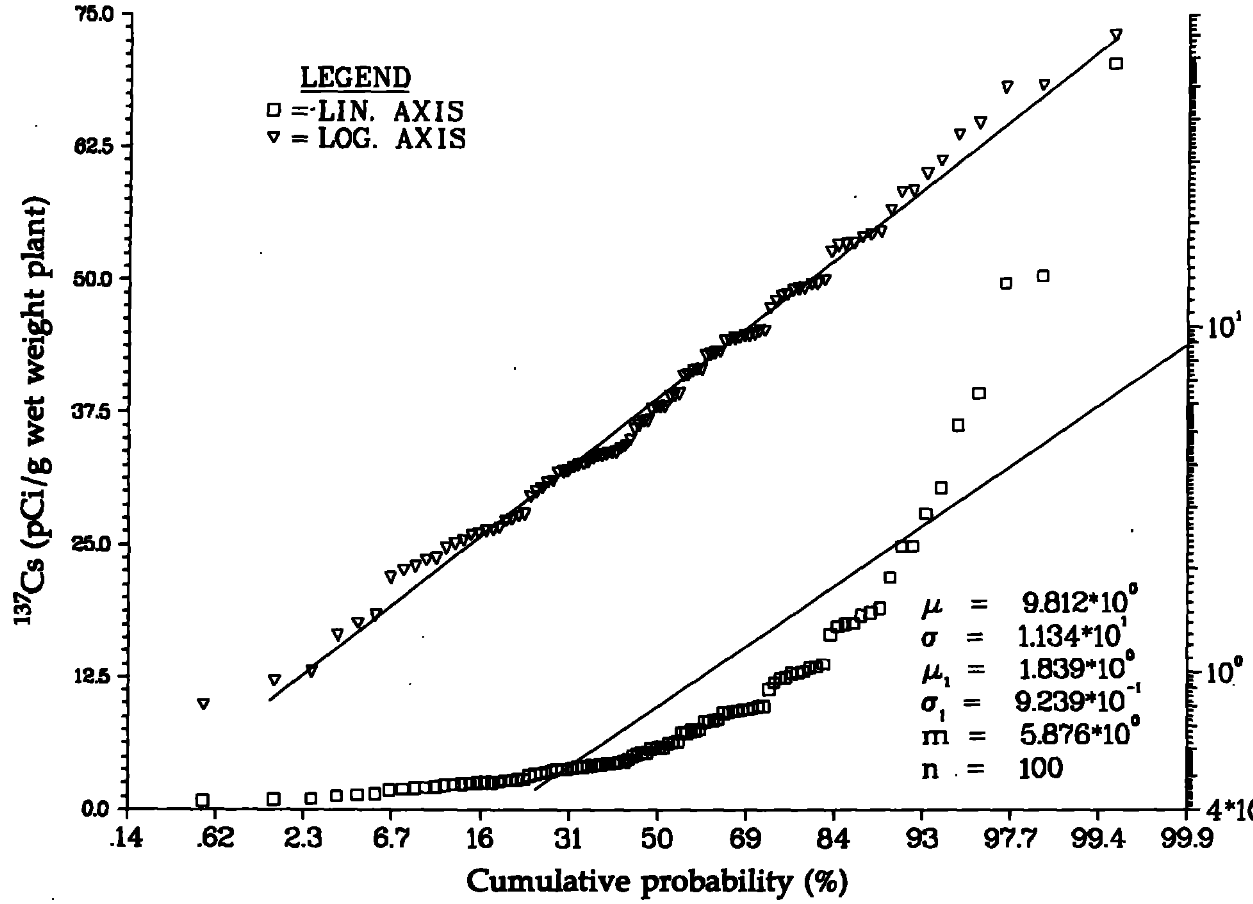


Figure 15. Log probability plot of ^{137}Cs concentration in drinking coconut fluid on Eneu Island.

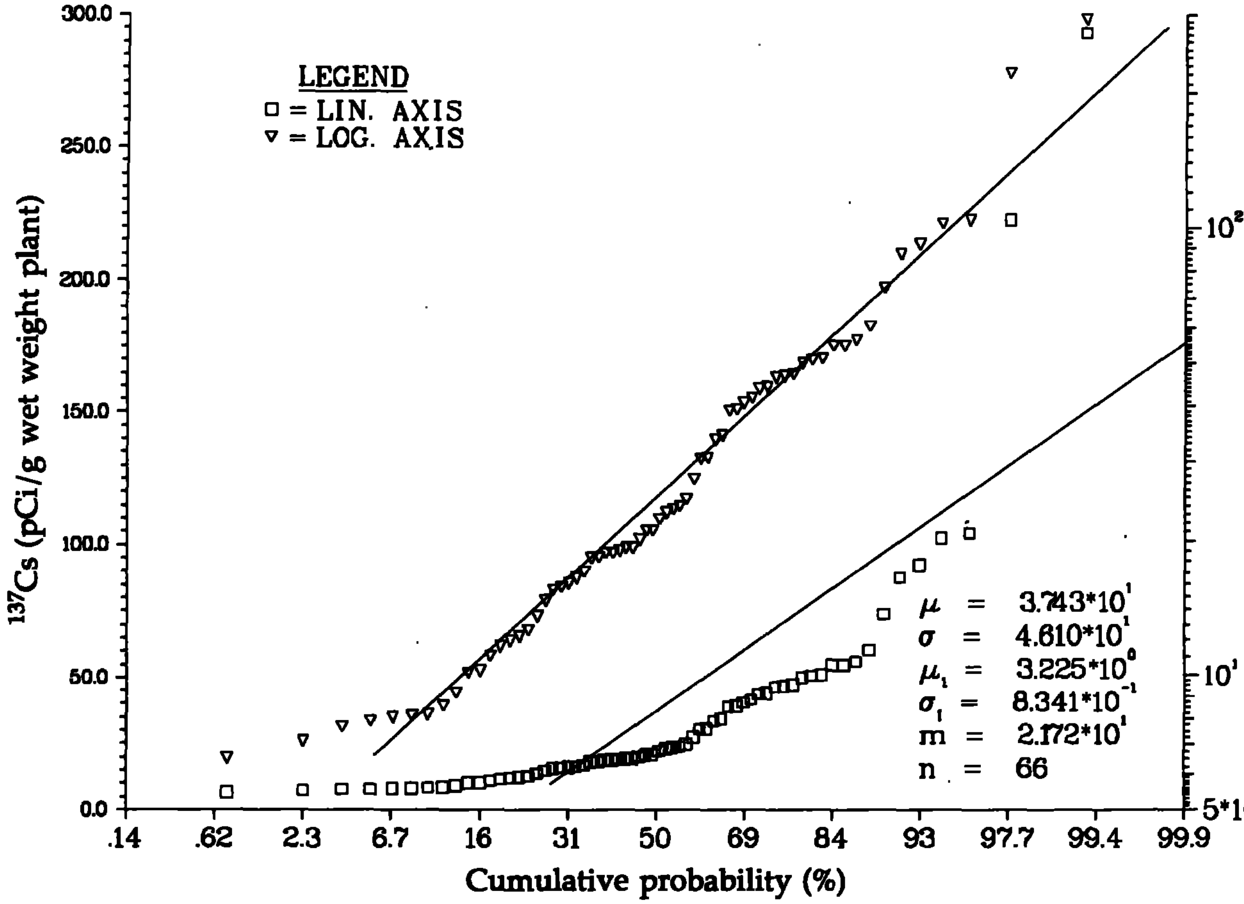


Figure 16. Log probability plot of ^{137}Cs concentration in copra meat on Eneu Island.

The equations used are:

$$q(t) = q(\phi) \sum_{i=1}^{N} A_i e^{-\alpha_i t} + f_1 f_2' I \sum_{i=1}^{N} A_i\left(1 - e^{-\alpha_i t}\right)/\alpha_i \,,$$

$$Q(t) = \int_o^t q(t) = q(\phi) \sum_{i=1}^{N} A_i\left(1 - e^{-\alpha_i t}\right)/\alpha_i$$

$$+ f_1 f_2' I \sum_{i=1}^{N} \frac{A_i}{\alpha_i}\left[t - \left(1 - e^{-\alpha_i t}\right)/\alpha_i\right] \,,$$

$$R = \frac{51.2E \times q(t)}{M},$$

$$D = \frac{51.2E \times Q(t)}{M},$$

where

I	=	intake rate (pCi/d)—concentration (pCi/g) x dietary intake (g/d),
$q(\phi)$	=	initial organ burden (μCi) at time $t = t_0$,
$q(t)$	=	organ burden (μCi) at time t,
$Q(t)$	=	cumulative activity at time t (μCi) since t_0,
f_1	=	fraction of ingested activity from gut to blood,
f_2	=	fraction of activity in blood to organ of interest,
A_i	=	fraction of q(t) in compartment i of organ,
B_i	=	biological elimination rate for compartment i of organ (d^{-1}),
λ	=	radioactive decay rate of nuclide (d^{-1}),
N	=	number of organ compartments,
α_i	=	$\lambda + B_i$ = effective decay rate of compartment i (d^{-1}),
M	=	organ mass (g),
E	=	effective energy of nuclide for organ (MeV),
51.2	=	units conversion factor,
R	=	dose rate at time t (rem/d), and
D	=	integrated dose at time t (rem).

The distributions of variables of interest I, B_i, and M are log-normal, while A_i is uniformly distributed. The values for the variables are generated using International Mathematics and Statistical Laboratory (IMSL) routines for log-normal and random (uniform) deviates. Each run generates the appropriate random numbers for each variable for calculating the dose. After storing the dose in the proper histogram bin, the procedure is repeated until 10,000 (or 100,000) trials have been made. The log probability (cumulative distribution) plot for the final doses is shown in Fig. 17.

In addition, the same input data were used with a totally different method for determining the distribution of the final dose based on the distribution of each of the model parameters.[43] In this approach, the distribution of each input parameter is expressed by a finite probability distribution (FPD), which is a discrete approximation of the continuous probability density function of the parameter. The dose, expressed as an FPD, is estimated by systematically combining the input FPDs in the dose model according to the rules of probabilistic arithmetic and storing the results in the proper, predetermined discrete output bins. This method gives very similar results and the graphic display of the final dose distributions from this MACRO code for the linear and log-transformed doses are shown in Figs. 18 and 19, respectively.

The average dose for Eneu and Bikini Islands presented here and calculated using mean values for all of the parameters in the model, falls at the 68th percentile on the distribution for both methods; that is, 68% of the population would be expected to have doses below this value. A dose equal to twice the average falls at the 88th percentile for both methods; a dose three times the average falls at the 95th percentile. Thus 68% of the population would have a 30-y integral dose less than 6 rem when imported foods are available. Based on this analysis, there is about a 5% chance for a person to receive a dose that is greater than three times the average dose.

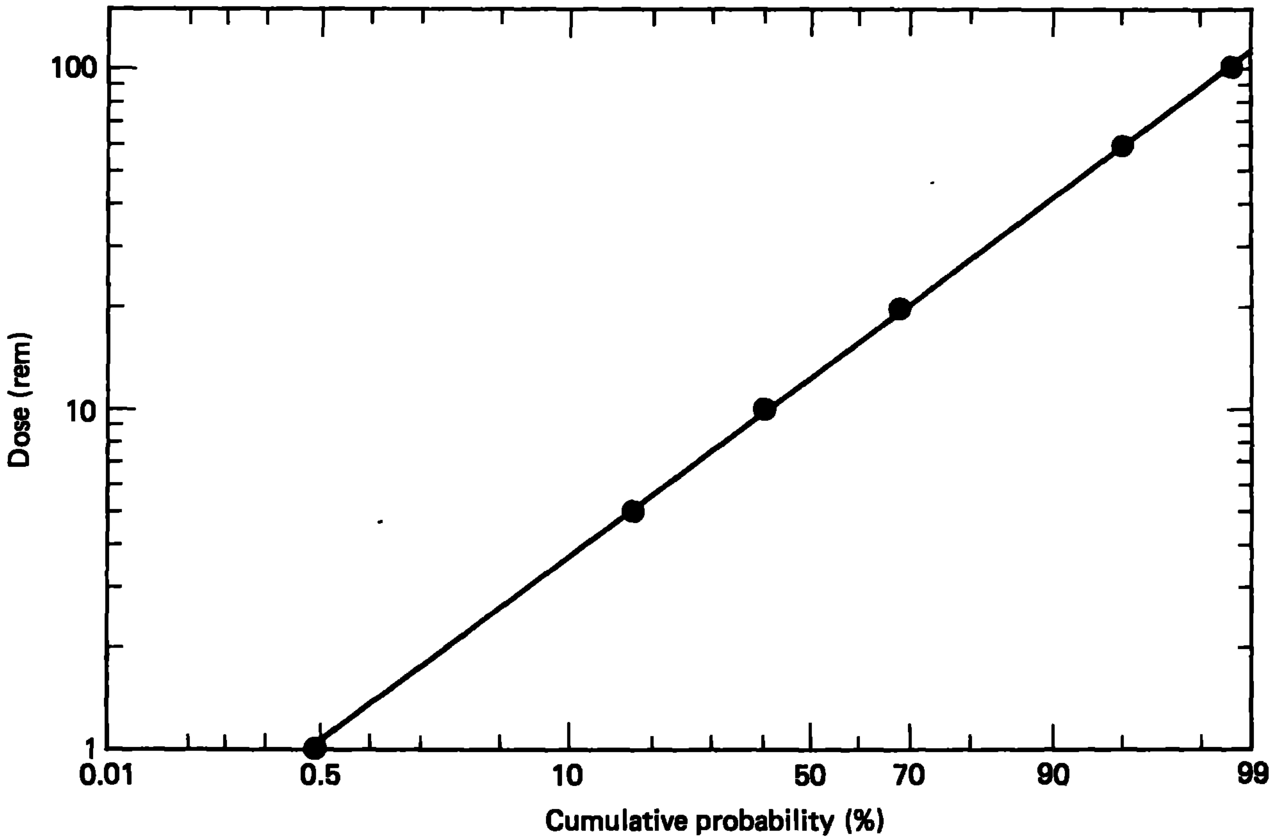


Figure 17. Log probability plot of 30-y integral doses with the Monte Carlo method. It is assumed that imported foods are available.

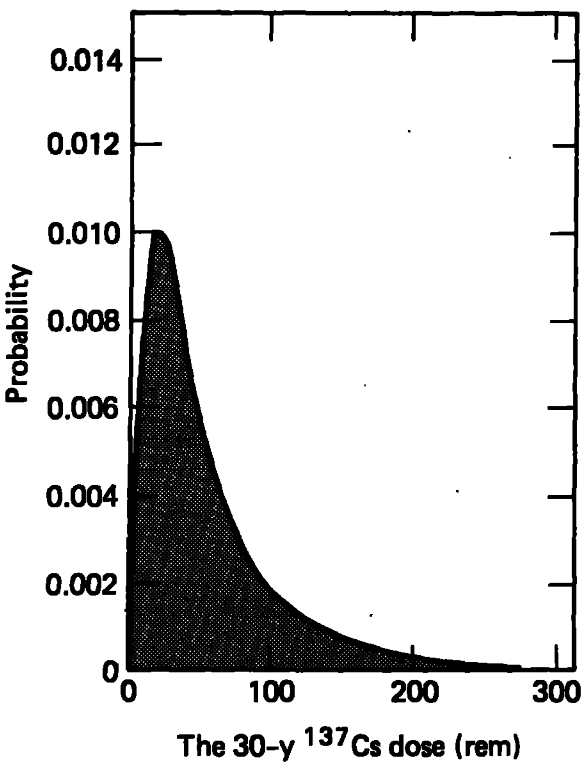


Figure 18. Linear plot of the 30-y integral doses calculated with the MACRO code.

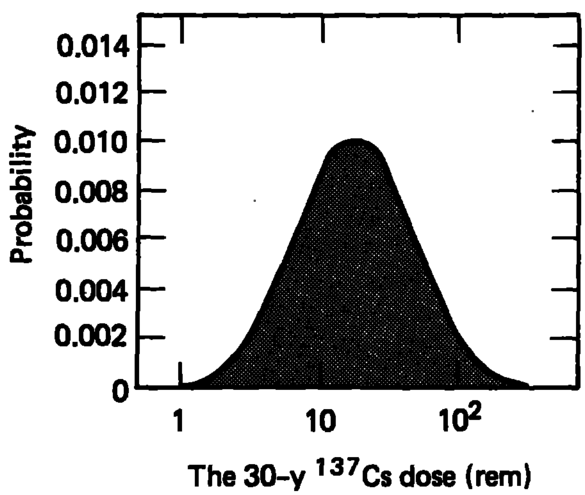


Figure 19. Log-transformed plot of the 30-y integral doses calculated with the MACRO code.

CALCULATIONS FOR DIETARY AND TIME VARIATIONS

There is always an interest in developing dose estimates for living patterns and options within living patterns other than those presented. An enormous number of options could be synthesized and it is, of course, impossible to include them all in one paper. We have developed those that we feel are most reasonable and most probable. However, we have in available appendices the data necessary to develop the predicted doses for other situations. If desired, one can calculate the external gamma, ingestion, inhalation, and dietary coconut contribution for any period of time, for either island, and for any fraction of the diet that one chooses by using the appendices.

Appendix B lists the annual gamma exposure in mrem/y and the cumulative or integral dose in rem for 1 through 70 y for Bikini and Eneu Islands. Therefore, once a time distribution on the islands has been established, the external dose can be computed from the data given in Appendix B.

Appendix C lists the doses via ingestion for Eneu and Bikini Island and the previously discussed alternate living patterns. The doses listed in this appendix can be used in conjunction with the other appendices to develop doses for alternate living patterns where time distributions or dietary intake are varied.

Appendix D lists the doses to the lung and bone from $^{239+240}Pu$, ^{241}Pu, and ^{241}Am as a result of inhalation when the individual spends 100% of the time on the listed island. The doses are based on the inhalation pathway model described in the text. Once again, when a time distribution on various islands has been established, the corresponding lung and bone doses for both dose rates and integral doses can be calculated from the data given in Appendix D.

Appendix E lists the whole-body and bone-marrow annual dose rates and integral doses for normal conditions (where imports are available) and the situation when imports are unavailable that results from the entire coconut intake coming from the listed island. The dietary intake of coconut can be prorated among the islands in any fashion desired and the resulting doses can be tabulated; the total dose resulting from any scenario can then be determined. The doses are, of course, based on the coconut intake listed for the imports-available and imports-unavailable diets in Table 13. Doses for other intakes can be determined by computing a ratio of the intakes and multiplying by the doses listed in Appendix E.

DISCUSSION

The doses we have presented are calculated assuming a return year of 1980. Because resettlement has not yet occurred, the doses will be reduced 2.3% per year from those listed in Tables 23 through 45, depending on when resettlement might begin.

The diet used to determine the daily intake of radionuclides is the most direct data available on the current dietary habits of the Enewetak people. Lacking direct dietary data for the Bikini people, we elected to use the results from the MLSC survey at Ujelang because of observed similarities in the Bikini and Enewetak life styles and because it was the only recent survey available when we made the dose calculations. The diet is of course very important in predicting doses to a population because the radionuclide intake and therefore the dose will correspond directly with intake of locally grown foods. We have mentioned in previous assessments the importance of the diet and the uncertainty that was inherent in previously constructed dietary patterns.[5,23,24] For the first time we have direct input from a significant number of the Enewetak population (144) as a function of age and dietary conditions. A recent report by the BNL on dietary habits at other Northern Marshall Islands atolls indicates the atoll-specific nature of the dietary intake and supports our concern that specific dietary information is needed for each atoll and each cultural grouping.[6] As an example, if the average coconut intake were assumed to be as high as the values listed for <u>prepared</u> coconut meat and fluid in the BNL report, then the estimated maximum annual dose rate would be about 2.7 times higher than those we calculated using the MLSC survey results when imports are available and 1.5 times higher when imports are unavailable. However, the BNL values are not necessarily appropriate for an average daily intake, and until specific dietary data are available for Bikini Atoll, the MLSC survey results appear to be reasonable estimates for these intakes.

The normal condition referred to here is the usual and expected living conditions in which the preferred imported foods are available. For the situation here where imported foods are unavailable, it is assumed that there is a primary dependence on locally grown crops for a person's lifetime, although some imported foods would in fact be available. <u>It is again emphasized that an accurate picture of the diet, especially the consumption rate of locally grown foodstuffs, is extremely important in the dose predictions for resettlement options at the atoll.</u>

Ingestion doses from ^{60}Co are negligible and therefore do not appear in any of the tables. Usually ^{60}Co is not detectable in vegetation samples. It is observed at low concentrations in soil samples but incorporation in plants is such that concentrations rarely exceed the detection limit. The ^{60}Co contribution to the external gamma dose is about 5% or less.

Doses from ^{90}Sr, ^{137}Cs, and ^{60}Co via the inhalation pathway are two to four orders of magnitude smaller than doses from the transuranic radionuclides and are therefore not listed in the dose tables.

Uncertainty in the final dose values can result from uncertainty in three sources of input data: (1) the radionuclide concentration in food (or soil); (2) the biological parameters such as radionuclide turnover times in the body, fractional deposition in various organs, and body or organ weight; and (3) the dietary intake.

First, the distribution of radionuclide concentration data in vegetation was discussed in Results and shown in Figs. 11 to 16. We have sufficient data to know that the average value will change little as we take more samples. The distributions are log-normal; the arithmetic mean $\bar{x}$ includes some 68% of the population, 2 $\bar{x}$ includes 88% of the population, and 3 $\bar{x}$ includes better than 95%. The number of food plants with a concentration three times the mean value is less than 5% of the total. Therefore, the probability of a person finding his entire diet for 1, 5, 10, or 30 y from food crops with a concentration of three times the mean value is very small. Soil concentration data are also log-normally distributed (see Figs. 9 and 10) with similar percentages accounted for by $\bar{x}$, 2 $\bar{x}$, and 3 $\bar{x}$ and reinforce those data observed in coconut meat and fluid; concentrations in plants should, overall, reflect the concentration in soil.

The observed log-normal distribution of radionuclide concentrations in soils and plants at the atolls is consistent with most elemental distributions in nature. Also the observation that three times the mean value includes more than 95% of the population distribution is consistent with other observations, several of which have recently been summarized by Cuddihy et al.[44]

The ^{90}Sr concentration distributions in bone have been specifically addressed by Kulp and Schulert.[45] They found that ^{90}Sr from fallout was distributed log-normally and that the 98th percentile value was 2.3 times the mean value. Maximum values observed for ^{90}Sr in bone by Bennett were three times the mean; that is, most of the data fell below three times the mean.[27-29] These data also reflect the combined variability of the ^{90}Sr concentration in food products and the variability in dietary intake.

The ^{137}Cs gamma-exposure data, which is listed in Refs. 1 and 7, shows that the maximum exposure rate observed at an isolated point on the island is, for most islands, less than three times the mean value. In many cases the maximum observed value is only two times the mean value. Because of the movement of people around their residence island, the variation of individual doses around the average dose is probably minimized and would not add much variability to distribution of doses calculated for the ingestion pathway. In addition, we have not included in the external doses listed in the tables the reduction in external exposure that would occur from spreading crushed coral around the houses and the actual shielding from the houses.

Second, the range of values observed for the retention of ^{137}Cs in humans has been summarized by the ICRP[34,35] and the NCRP.[36] For example, the range of observed values for the retention time for the short-term compartment is 0.5 to 2.1 d with a mean of 1 d; the upper limit that has been observed is greater than the mean by only a factor of two. For the long-term compartment, the data range from 60 to 165 d with a mean value of 110 d; the maximum value in this case is less than twice the mean value. The fraction of the intake that has been observed to go to the short-term compartment (i.e., 2 d) ranges from 0.02 to 0.22 with a mean of 0.1; for the long-term compartment (i.e., 110 d) the range is 0.78 to 0.97 with a mean value of 0.9. For both cases the maximum value is less than twice the mean.

Third, the dietary intake of local foods is a major source of input data that is somewhat uncertain and that could lead to higher average doses than presented here if the average intake were significantly greater than we have assumed. For example, if the current lifestyle should change drastically with a total reliance on local foods, then the average doses would be nearer those listed for the imports-unavailable scenario. This is a very unlikely occurrence because the people have a source of income, and imported foods are now considered a staple and a necessity, not a luxury. The people will have access to outside goods and will trade with either the United States or other world governments.

Even if the use of imported and local foods remains as it currently is, there is a possibility that the average intake of local foods could be greater than we have assumed in our model diet--for example, if the entire BNL diet rather than the MLSC results were assumed to apply to Bikini Atoll. The reasons for our selection of the dietary intake used here are discussed above in Limitations of the Asessment. There are sufficient data available for the other model parameters to know that as the data bases increase, the average value will change little.

Previous evaluations indicate that dietary intake in a population is log-normally distributed. Our evaluation of the MLSC survey confirms the log-normal distribution of dietary intake (Figs. 6 and 7). The distribution of doses is also log-normal and the mean dose calculated using the average value for all model parameters falls at about the 68th percentile; that is, 68% of the population would be expected to have a dose at or below the listed mean value. A dose equal to twice the mean value will include 88% of the population. It is important to recognize when we talk about the average doses here that they are not at the midpoint (50% point) of the distribution.

There are several reasons why the average doses presented here might be lower. These include the following.

(1) The doses are calculated assuming a return year of 1980. Doses would be expected to be about 2.3% lower per year until resettlement occurs based on the radiological decay of cesium and strontium.

(2) We still do not know the environmental residence time of cesium in the atoll ecosystem. If it were 30 y--that is, equal to the radiological half-life--then the estimated doses would be half (50%) of those presented in the tables. If the environmental residence time were as long as 50 y then the doses would be 34% lower and if it should be as short as 20 y the estimated doses would be 64% lower. We have experiments under way to determine the environmental residence time and when data are available, they will be included and the estimated doses adjusted accordingly.

(3) We have not included shielding from external gamma exposure that occurs from the housing structure and from coral gravel that is commonly spread in a 10- to 15-m area around the houses. The people do spend considerable time around and in their houses.[1] Therefore, a significant reduction in the external exposure around the housing area can occur. This reduction from shielding by the house can be a factor of two based on a 30 to 40% occupancy. If coral gravel is spread around the house, another factor of two reduction can be obtained. Depending on the location of the housing, the use or non-use of coral gravel, and the percentage of time spent in or near the house, the external dose reduction could range from 15 to 80%.

(4) We have used the average values for all of the parameters in the dose models and the resulting doses fall at about the 68% point on the distribution. If we used the median values to estimate the doses for the midpoint of the distribution, the doses would be lower.

(5) If there should be a greater reliance in future years on imported foods with a concurrent decrease in consumption of local foods, then the estimated doses would be lower.

A significant feature of the dose analysis here is the tremendous reduction in potential dose if resettlement occurs on Eneu rather than Bikini Island. About 60% of the predicted dose results from ^{137}Cs ingested from consumption of coconut meat and fluid. The ^{137}Cs concentration in coconuts is much lower on Eneu than on Bikini. For the Eneu option, maximum annual dose rates and 30-y integral doses are less by nearly a factor of eight than for the Bikini option. Again, this emphasizes how important the local diet is in determining doses at the atoll (particularly the coconut intake) and the importance of imported foods in reducing potential doses.

Two scenarios were used in the reassessment of Enewetak Atoll for estimating the dose to children.[46] The estimated dose for a case where the child is born at the time the people return is greater than that where the child is born after return, even though in the Enewetak assessment it was assumed that there was a large increase in the availability of locally grown food products 8 y after return. The maximum dose case from birth through 70 y leads to estimated doses that are less than those predicted for adults using the results of the MLSC diet survey. The doses calculated for children for Bikini and Eneu Islands are also less than those calculated for adults as can be seen by comparing the adult doses in Tables 23, 24, 27, and 28 with the child doses in Tables 42-45, respectively.

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